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2d Session

COMMITTEE PRINT

REPORT ON

MARINE HYDROTHERMAL METAL DEPOSITS

PREPARED BY

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SUBMITTED BY

Honorable WALTER B. JONES, *Chairman,* Full Committee

AND

Honorable JOHN B. BREAUX, *Chairman*

SUBCOMMITTEE ON FISHERIES AND WILDLIFE
CONSERVATION AND THE ENVIRONMENT

TO THE

COMMITTEE ON MERCHANT MARINE AND FISHERIES

JULY 1, 1982

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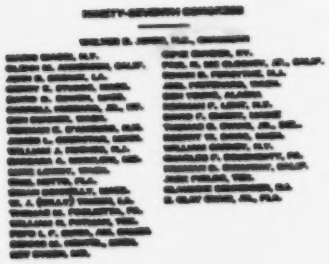

U.S. House of Representatives
Committee on
Merchant Marine and Fisheries
Room 1334, Longworth House Office Building
Washington, D.C. 20515

December 18, 1981

Mr. Gilbert Gude
Director
Congressional Research Service
Library of Congress
Washington, D.C. 20540

Dear Mr. Gude:

With the passage and enactment of the Deep Seabed Hard Minerals Act of 1980, the resources of the seabed have been opened as a new frontier for human activity. We are coming to realize, however, that those resources are not limited to the manganese nodules alone to which our attention was fixed during that law's history. Other strategic minerals and materials are surfacing as future resources we may capture from the sea. Bearing this rich -- yet untested -- opportunity in mind, we write you to request that Jan Van der Voort of the Congressional Research Service prepare a report for the Committee on Merchant Marine and Fisheries that analyzes present knowledge and potential exploitation of polymetallic sulfides.

We envision this report to be a comprehensive summary of the research performed to date and knowledge of polymetallic sulfides. Included in its contents should be discussion of their location, formation, research and technology for extraction, application to land sources, economics of exploitation, and juridical framework governing the access to these materials. The enclosed outline reflects the contents we consider essential. It should be a sustantive document for the use of legislators as we deliberate in the future how to ensure exploration and mining access to groups who further the national interest in bringing polymetallic sulfides to the strategic uses of our country.

Our staff will be pleased to work with your specialists as they may need to consult during the stages of writing the report. Please feel free to contact Claire Fronville of the Full Committee staff at 226-3547 and Tim Smith of the Subcommittee on Fisheries and Wildlife Conservation and the Environment at 226-3522 with any questions.

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It would be most helpful if the Congressional Research Service could complete this report by the end of February and make copies available to the Committee to facilitate our legislative plans for the remainder of the 97th Congress. We look forward to working with you closely on this request and eagerly anticipate the useful product your skilled experts will deliver.

With warm regards, I am

Sincerely yours,

Walter B. Jones
Chairman
Committee on Merchant Marine
and Fisheries

John B. Breaux
Chairman
and Wildlife Conservation
and the Environment

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LETTER OF SUBMITTAL

June 8, 1982

Honorable Walter B. Jones
Chairman, Committee on Merchant
Marine and Fisheries
Committee on Merchant Marine and Fisheries
House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

I am pleased to submit, as requested, this report on the newly discovered and scientifically exciting polymetallic sulfide deposits that are forming in active hydrothermal vent areas of the ocean floor. The purpose of this report is to provide a substantive document for the use of legislators in future deliberations as to how to ensure equitable, orderly, and environmentally responsible exploration and potential mining access to the polymetallic sulfide deposits lying within and beyond a 200-mile coastal zone of the United States. In pursuit of this objective, the report provides a comprehensive summary of the current state of knowledge regarding these deposits including a discussion of their location, formation, research, and technological approaches for extraction, application to land-based deposits and future exploration, economic potential for commercial recovery, and juridical framework governing the access to these minerals.

This report was prepared by Jan L. Van der Voort and James E. Mielke of the Science Policy Research Division with contributions from Sally L. Frodge of the University of Washington. Ms. Van der Voort was responsible for the overall direction and coordination of the project under the general guidance of Dr. Mielke.

We hope that this report will serve your committee's needs as well as those of other committees and Members of Congress concerned with the future development potential of this mineral resource.

Sincerely,

Gilbert Gude
Director

Congressional Research Service
The Library of Congress

Washington, D.C. 20540

LETTER OF SUBMITTAL

June 8, 1982

Honorable John B. Breaux
Chairman, Subcommittee on Fisheries
and Wildlife
Committee on Merchant Marine and Fisheries
House of Representatives
Washington, D.C. 20515

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Sincerely,

Gilbert Gude
Director

Congressional Research Service
The Library of Congress

Washington, D.C. 20540

MARINE HYDROTHERMAL METAL DEPOSITS

Prepared by

Jan L. Van der Voort
Analyst in Science and Technology

and

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Science Policy Research Division

June 8, 1982

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I. SUMMARY

Marine hydrothermal metal sulfide deposits associated with active vent systems on the ocean floor are newly discovered features of considerable scientific interest and potential economic value. The recent discovery of these ore-forming fluids venting into the ocean in spreading centers or rift zones is not so much of a surprising accident as it is the product of years of scientific investigation, research, and testing of hypotheses regarding the separation of oceanic plates.

The location of the deposits is of interest to the scientific community because of the intimate relationship between the activity at the spreading centers and large scale, world wide processes of crustal evolution. The location is also of interest to those who consider the economic potential of seabed resources, particularly resources in reasonable proximity to the coast of the northwestern United States.

Much of the excitement over marine polymetallic sulfide deposits stems from the expectation that understanding the conditions that have resulted in their formation may lead to better prediction of other marine deposits and understanding of processes that formed similar terrestrial ore bodies. The mineralization process involves the percolation of ocean water downward through fractures in the crust where it is heated at depth, leaches metals, and as a hot metal-laden brine returns to the cold ocean floor where the metals are deposited. The mineral deposits of the ridge systems form crusts

along faults and at the surface, as well as chimneys ranging from a few inches to 100 feet in height and up to 30 feet in width. Where chimneys have coalesced a massive deposit over 100 feet in thickness, 600 feet in width, and over one-half mile in length has been observed. In the Guyamas Basin in the Gulf of California, hydrothermal activity is not only depositing sulfides but creating petroleum through thermal cracking of organic material in the sediment.

In addition to the mineralization, active vent areas host an unusual variety of exotic life forms. In what seems like a very hostile environment--very high pressures, extremes in temperature, highly toxic concentrations of hydrogen sulfide, and lack of sunlight as an energy source--the biota thrive. These biota include foot-long clams, peach-colored jellyfish resembling dandelions, six-foot-long tube worms, and a variety of crabs and fish. These biota rely in large measure on the hydrothermal processes that produce sulfur compounds through bacteria that can digest sulfur in combination with carbon dioxide and oxygen to synthesize proteins and other organic compounds.

In the last twenty years, technological developments in areas such as sonar mapping, deep ocean photography, and submersible research vessels have opened up a new world of the deep ocean floor for exploration. The history of the research and recent vent discoveries exemplify not only the vastness of the oceans' unknown, but also illustrates many important aspects of the development of modern oceanographic research such as: (1) evolution of a truly multidisciplinary field of science; (2) coordination and cooperation of a variety of government and academic groups; (3) international cooperation and support, often involving multinational research

projects; and (4) use of expensive and sensitive technology. Among the systems at the forefront of the current generation of deep sea research technology are the DSRV (Deep Submergence Research Vehicle) Alvin, the SEABEAM sonar mapping system, and the ANGUS (Acoustically Navigated Geological Underwater Survey) camera system.

At the present time too little is known of the marine polymetellic sulfide deposits to project their economic significance beyond a general expectation of future potential. The possible dimensions of that potential are, however, beginning to attract some interest. No systematic surveys of the volume and grade of any of the deposits have been undertaken and no detailed economic evaluation of these deposits or potential recovery techniques have been made. Consequently, on the basis of current data, extrapolation of possible dimensions and grade of the known deposits into uncertain dollar values would not be considered justifiable. Exclusive of the Red Sea only four of the spreading sites sampled have been found to contain what appear to be massive deposits of polymetallic sulfides: Juan de Fuca, Guaymas Basin, East Pacific Rise at 21 degrees N; and Galapagos Rift. To date, sampling activities at these four sites has yielded a total of about 1,000 pounds of material. The major metals of economic importance appear to be copper, silver, and zinc with lesser amounts of lead, iron, manganese, molybdenum, vanadium, and others.

If the extent of potential metals recovery from polymetallic sulfide deposits is unknown, or speculative at best, the cost of mining them using an undefined technology is even more speculative at this time. However, some suggestion of the possible magnitude of the costs involved might be

gained from comparison or contrast to the projected costs of deep seabed manganese nodule mining. Capital and annual operating costs of mining, transport, and processing for both types of ventures could be comparable with some differences tending to counterbalance one another or possibly favor hydrothermal deposits. These differences would likely involve higher extraction costs for polymetallic sulfide deposits from having to first break the deposits into pieces which can be raised to the surface. On the other hand, the shallower depth of the hydrothermal deposits (about one-third the depth of nodule mining) would tend to reduce mining costs. The more concentrated nature of hydrothermal deposits versus the more dispersed nature of nodule formation may be an advantage for polymetallic sulfide recovery. If the minesite were in the Gorda or Juan de Fuca Rift, transportation costs to the U.S. mainland would be lower. Also polymetallic sulfides could be processed in existing smelters rather than requiring new and more complex processing facilities.

Among the marine hydrothermal metal deposits, the Red Sea metalliferous muds have not attracted much attention internationally, but they may become the location of the first deep sea mining operation. A factor which favors the prospect of expeditious development in the Red Sea is the Saudi Arabia-Sudanese agreement, concluded in 1974, to hold joint equal and exclusive sovereign rights to economic development of a designated common zone in the central Red Sea below water depth of 1,000 meters (3,300 feet). The resource consists of thick layers of metal-bearing muds rich in silver, zinc, and copper lining the bottoms of pools of dense hot brines.

The discovery of what may prove to be a major new source of metals from the marine environment raises a number of issues, not all of which are limited exclusively to development of polymetallic sulfide deposits. In the broadest sense, the issue may be addressed as a question of jurisdiction over marine resources not previously identified in domestic legislation or international agreements. Of the legal framework, that exists, some basic questions may be asked:

- To what extent does the domestic and international legal framework pertain to or include marine polymetallic sulfide deposits?
- How adequately does it address any of the needs that are unique to polymetallic sulfide minerals recovery?
- Is it appropriate to modify the existing domestic legal framework to include marine polymetallic sulfide deposits?

Environmental issues are another area of congressional concern. Two basic questions are:

- To what extent are possible environmental impacts of hydrothermal metals mining defineable?
- What further research, if any, is needed in this regard?

II. GEOLOGY, GEOGRAPHY AND FORMATION OF POLYMETALLIC SULFIDE DEPOSITS

"Polymetallic sulfide" is a popular term that has been given to metal-bearing minerals that have been identified in geologically active areas of the ocean floor. The potential for economic value has heightened interest in the character and generation of the deposits as well as their location, some within 200 mile coastal zones.

Discovery of the sulfide deposits was not a surprise, but rather confirmation of years of research and suggestions regarding geological and geochemical processes at the ocean ridges. Research related to: (1) separation of oceanic plates, (2) magma upwelling at the ocean ridges, (3) chemical evolution of seawater, and (4) land-based ore deposits that were once submarine, has contributed to, and culminated in, hypotheses of seawater circulation and mineral deposition at ocean ridges that closely fit recent observations.

LOCATION

The metal sulfide deposits are found in geologically active areas of the ocean floor called rift zones or spreading centers where new ocean floor is being created. The spreading centers delineate some plate boundaries, covering over 40,000 miles or 25 percent of the earth's surface (figure III-1). The deposits have been found at depths ranging from 6,500 to 8,500 feet. The extent of the sulfides is not known but they have been identified in a number of areas such as: the Galapagos Rift (240 miles east of the Galapagos Islands and about 350 miles west of Ecuador); the Red Sea; the East Pacific Rise area (13 degrees

and 21 degrees North) off the coast of Mexico; the Guaymas Basin in the Gulf of California; and the Juan de Fuca Ridge off the Northwestern coast of the United States (figure II-2 and table II-1).

The location of the deposits is of interest to the scientific community because of the intimate relationship between the activity at the spreading centers and large scale, world wide processes shaping the earth's evolution. Some of the questions being asked are:

1. Why is there extensive sulfide mineralization in some areas and not others?;
2. What does the mineralization imply or indicate about the processes deeper in the earth?; and
3. Is it possible to predict the location of (as yet) undiscovered deposits based on the similarities of the deposits that have been studied?

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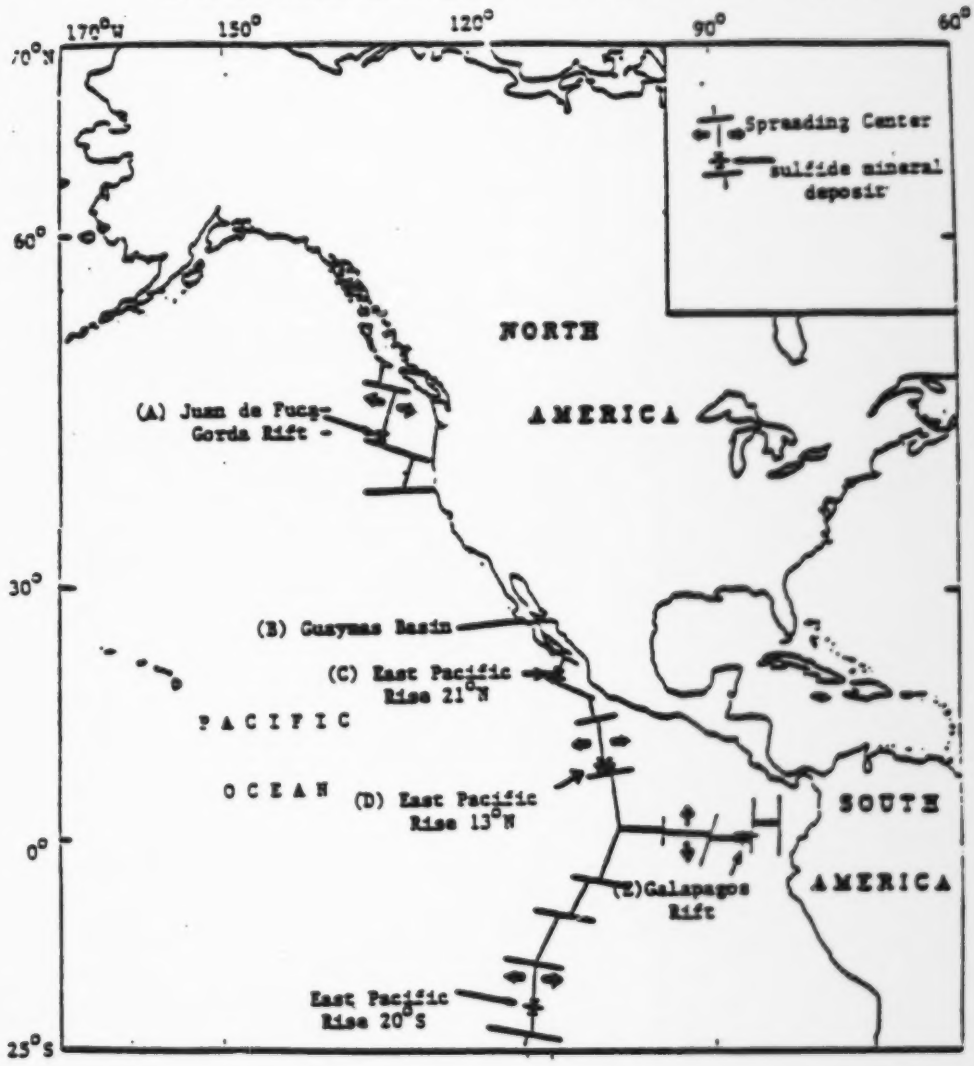
FIGURE II-2
Map of East Pacific Spreading Centers and Polymetallic Sulfide Deposits



Source: Edgar, N. Terrence, Office of Marine Geology, United States Geological Survey, National Center, Reston, VA, (Personal Communication, December 1981)

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TABLE II-1

Seafloor Sulfide Deposits

AREA:	A	B	C	D	E	F
Name of area:	Juan de Fuca Ridge	Guaymas Basin	East Pacific Rise 21° N	East Pacific Rise 13° N	Galapagos Rift	East Pacific Rise 20° S
National involvement:	USA	USA	USA	France	USA	USA
Date of initial discovery of deposit:	1981	1980	1978	1981	1981	1981
GRADE:	(a)	(a)	(a)		(b)	
% Zinc	55.0	30.0	49.7	French researchers have photographed hydrothermal vents and associated mineral deposits. No details are available at this time.	0.1	U.S. researchers photographed active hydrothermal systems similar to the East Pacific Rise 21 N site. No samples were obtained.
% Copper	0.35	1.0	0.75		10.0	
% Lead	0.32	0.1	0.35		0.1	
ppm Silver	300	300	400		300	
Future funded research:	USA	USA, Mexico Jan. 1982	USA, Mexico, France Nov. 1981	France Jan. 1982	---	---

(a) USGS analyses.

(b) NOAA press release.

Source: N. Terrence Edgar, Office of Marine Geology, U.S. Geological Survey, National Center, Reston, VA (personal communication, Dec. 1981).

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Those interested in the economic potential of the minerals are interested in the location of the deposits because of their close proximity to the coast; the Galapagos Rift is about 240 miles off the coast the Galapagos Islands and the Gorda Ridge, an area of potential mineralization, is within 200 miles of the coast of the northwestern United States. As with the deep sea manganese nodules the location of the polymetallic sulfides raises questions of jurisdiction over seabed resources at a domestic and international level (see chapter V for further discussion).

FORMATION OF THE DEPOSITS

Much of the excitement over the marine polymetallic sulfides stems from the dynamic nature of the processes of formation and their role in hypotheses of earth evolution. Through understanding the conditions that have resulted in the formation of these marine sulfides, scientists not only can better predict the occurrence of other marine deposits but they better understand the processes that formed similar terrestrial deposits.

To appreciate the intimate relationship between hydrothermal vent mineralization and larger scale earth dynamics, the process must be considered in the context of plate tectonics. Plate tectonics is a general term to denote movement of "plates" of the earth's crust on a more viscous inner material, throught to be driven by large convective cells within the earth. The formation of mountains such as the Hymalayas, rift zones such as the Red Sea, volcanoes such as those in Iceland, and spreading centers are thought to be expressions of this dymamic process.

The spreading centers are areas where molten rock (less dense than the solid, cold ocean crust) is rising to the sea floor from depth, while the plates are moving apart. The plates move apart from one another at different rates, from one to six inches per year. The sulfides have been obeerved in areas of medium-fast spreading rates (2-6 inches per year). It is estimated that 7,800 miles of fast spreading regions exist, principally in the Pacific Ocean.

The mineralization process involves the interaction of ocean water with the molten rock. Very simply, ocean water percolates downward through fractures in the solid ocean crust, heated at depth it interacts with the rock, leaching metals. Key to the creation of an ore deposit, the metals become more concentrated in the percolating water than they are in the surrounding rocks. The hot (300 to 400 degrees Centigrade) metal-laden brine moves upward, mixes with the cold ocean water (2 degrees Centigrade) and the metals percipitate forming sulfide minerals along cracks, as crusts on the ocean floor or as chimneys or stacks (figure II-3). This high temperature suggests little or no mixing with cold seawater before the solutions exit through the vents. 1/

1/ Ballard, R., et al. East Pacific Rise at 21 Degrees North: The Volcanic, Tectonic, and Hydrothermal Processes of the Central Axis. Earth and Planetary Science Letters, 55, 1981, p. 1-10.

The degree to which the ore solution is diluted in the subsurface is dependent on the porosity or fracturing of the near surface rock and determines the final exit temperature and composition of the hydrothermal fluids.

The fluid ranges from manganese-rich in extreme dilution to iron-dominated at intermediate levels to sulfide deposition when little dilution occurs. In support of these observations investigators have found sulfide deposition at the vents with manganese oxide deposits farther away from the seawater-hydrothermal fluid interface. 2/ Iron oxides are often found in association

---

2/ East Pacific Rise Study Group, Crustal Processes of the Mid-Ocean Ridge, Science, vol. 213, July 1981, p. 31-40.

---

with, but at a distance from, the active vent and sulfide mineralization.

GEOLOGY

The sulfide deposits can be related by several basic features and also by hypotheses regarding their formation. There are, however, significant differences in form and composition. Rather than providing a detailed geologic description of the sites, the emphasis in this report will be on the similarities of these deposits and how this may lead to further understanding of global processes and identification of new deposits.

The deposits have been found along ocean spreading centers, part of the mid-ocean ridge system. These areas are geologically active; current or recent volcanic activity and earthquake activity are often associated. High heat flow, extensive fracturing in the oceanic crust, along the ridges and chemical anomalies are typical.

The mineral deposits of the axial ridge systems form crusts along faults and at the surface, as well as chimneys in close proximity to the axial rift

Declassified

zone. Chimneys ranging from a few inches to 100 feet in height and up to 30 feet in width have been observed (figure II-4). The ridge systems are topographic highs, rising up from the ocean floor. The topography is influenced by faulting, often resulting in scarps or walls of rock, and by chimneys formed by hydrothermal vent deposition. At the Galapagos site the chimneys have coalesced and some of the minerals have been redeposited resulting in a massive deposit of sulfides estimated to be about 100 feet thick, 600 feet wide and over one-half mile in length. 3/

3/ Malahoff, A. Polymetallic Sulfides from the Oceans to the Continents. Sea Technology, Jan. 1982, p. 51-55.

The term "polymetallic sulfide" refers to the composition of the minerals: many metals (polymetallic) and sulfur (sulfide) leached from the rocks at depth and deposited at the seafloor. The minerals are similar to these found on land and mined for their metal content. Analysis of the minerals indicates that they contain varying amounts of copper, zinc, lead, silver, vanadium, cadmium, and other metals (Plate 1). Distinctive yellow orange iron oxides and hydroxides are often associated with the sulfides at some distance from the vents. 4/

---

4 / Hekinian, R. et.al. Sulfide Deposits from the East Pacific Rise Near 21 Degrees North. Science, vol. 207, Mar. 28, 1980.

In several locations the chimneys are still active, spewing white, milky water containing iron sulfide, barium sulfate and silica, or black water laden with sulfide precipitates (Plates 2 and 3). The volume of water associated

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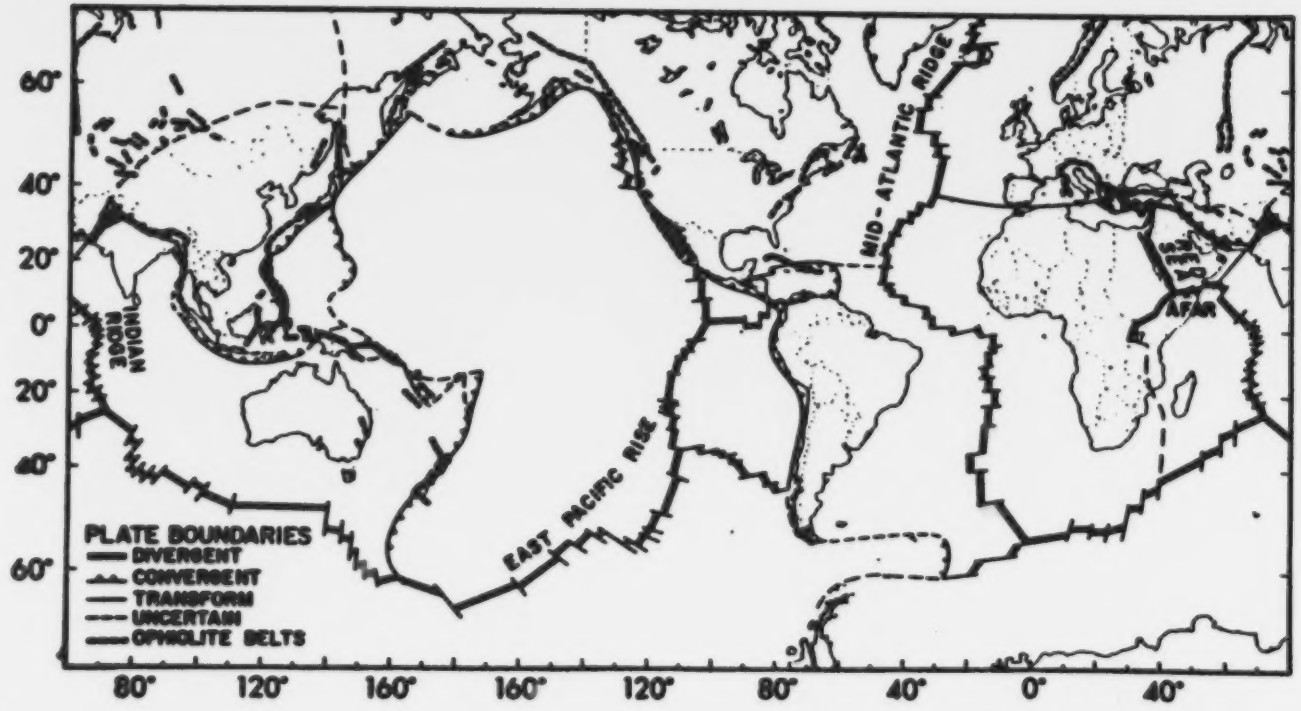
FIGURE II-1. Plate Boundaries.



Source: Rona, Peter. Criteria for Recognition of Hydrothermal Mineral Deposits in Oceanic Crust. Economic Geology, Vol. 73, No. 2, March-April, 1978, p. 135-160.

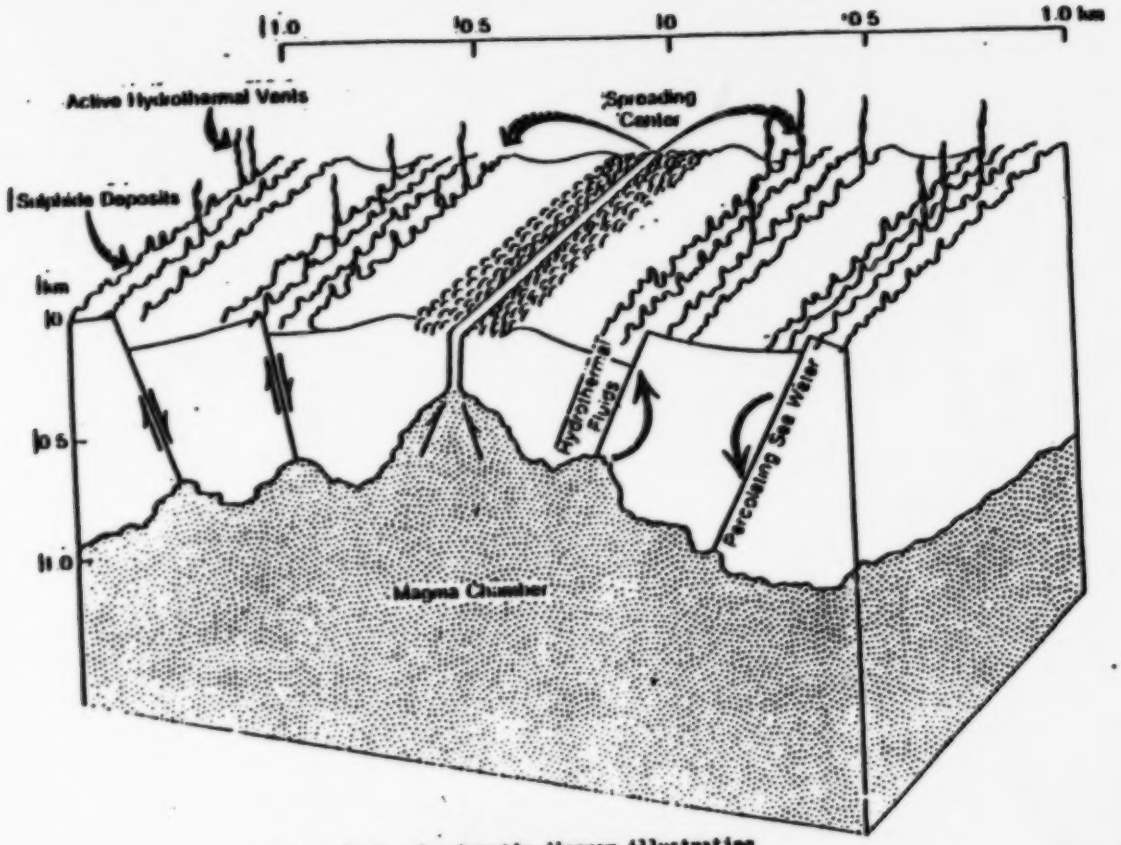


Figure II-3. A schematic diagram illustrating a spreading center and associated vents and magma chamber.

Source: Barrows, Joan. Polymetallic Sulphides Frontiers in Ocean Mineral Exploitation Annual Meeting of Assoc. of American Geographers, San Antonio, April 26, 1982.

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with this circulation is estimated to be equal to the entire ocean volume passing through this zone approximately every eight million years. 5/ These vent areas

5/ East Pacific Rise Study Group. Crustal Processes of the Mid-Ocean Ridge, Science, vol. 213, July 1981, p. 31-40.

offer a rare opportunity for observation of ore formation in action. Although deposition rates are highly speculative, some of the chimneys that have been observed are immense and the vents are thought to be relatively short lived (several decades) which would imply very rapid deposition rates. Investigators have observed growth of one foot in two years in a chimney in the Galapagos Rift. 6/

6/ UN/DIESA Ocean Economics and Technology Branch. Polymetallic Sulphides: More Riches From the Sea? United Nations, Mar. 1982.

THE GUAYMAS BASIN: A SPECIAL CASE

The basin hydrothermal processes described earlier are most likely occuring in the Guaymas Basin in the Gulf of California, but the thick layers of sediments (thousands of feet) change the environment significantly from the Pacific locations mentioned previously which are virtually free of sedimentation at the ridge crest. There are a number of factors influencing the mineral deposition in the Basin; it may prove to be more variable and complex than the other hydrothermal deposits. Rather than dispersal of the metals into seawater, the metals are trapped in the sediment in a manner perhaps

more similar to the Red Sea deposits described in chapter IV. Also as with the Besshi ore deposits of Japan, a rich source of copper as well as some gold and silver, the sediments are interlayered with volcanic rocks and veins of metallic ores. 7/

7/ Edmond, J.M. Hydrothermal Activity at Mid-Ocean Ridge Axes. Nature, vol. 290, Mar. 12, 1981, p. 87-88.

The combination of rapid sedimentation, intrusion of hot rock and abundant organic debris in the basin may be resulting in a rapid breakdown or thermal cracking of the organic debris into light petroleum which have been found in high concentrations in some cores. 8/ The Guaymas Basin is highly unusual in hosting both metalliferous hydrothermal deposits and petroleum formation.

8/ Sullivan, Walter. Divers Find Natural Oil Refineries. New York Times, Jan. 29, 1982.

ASSOCIATED MARINE BIOTA

At depths that are typically almost barren of animal life, some of the hydrothermal vent areas host a variety and abundance of unusual life forms. Foot-long clams and mussels, peach colored jellyfish resembling dandelions, six-foot-long tube worms, crabs, and several species of fish are among the inhabitants (plates 4, 5, 6, and 7).

In what seems like a hostile environment-very high pressures, extremes in temperature, highly toxic concentrations of hydrogen sulfide, and lack of

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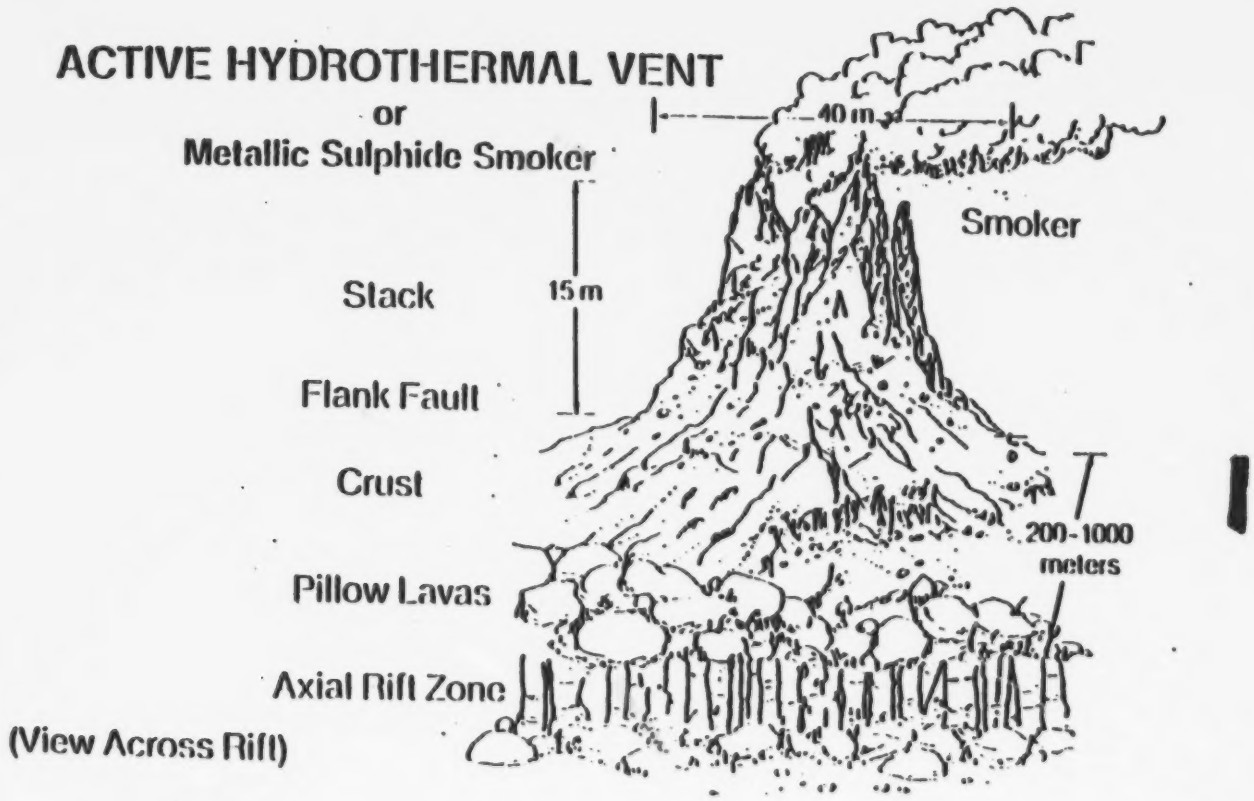
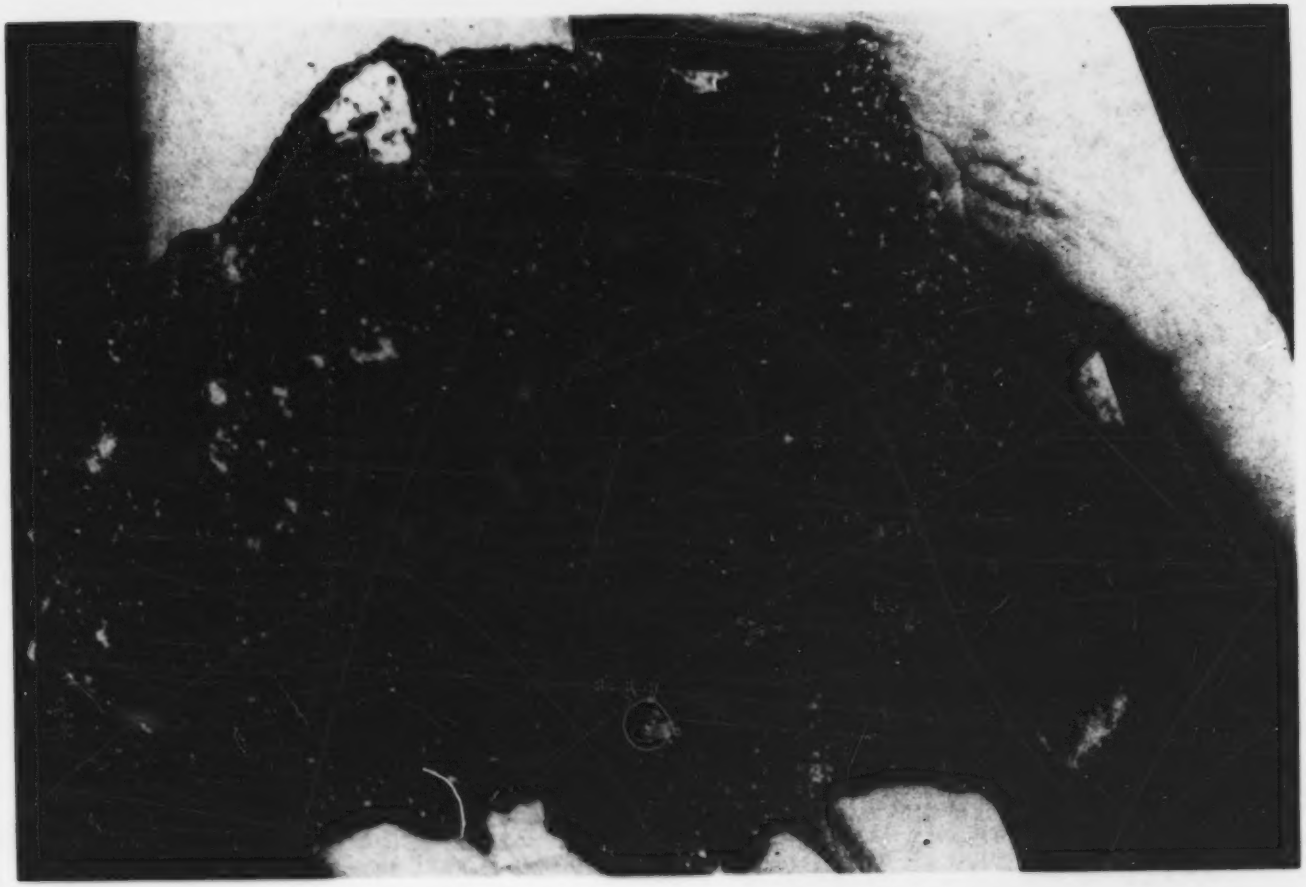


Figure II-4. An active hydrothermal vent.

Source: Barrows, Joan. Polymetallic Sulphides Frontiers in Ocean Mineral Exploitation. Annual Meeting of Assoc. American Geographers, San Antonio, April 26, 1982.

Plate 1. Specimen from the ocean floor at the East Pacific Rise containing iron and silver sulfides and many other metals.
(Photo courtesy of the National Science Foundation)



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Plates 2 and 3. Active hydrothermal vents, "black smokers," at the East Pacific Rise spewing hot metal-laden brine solutions onto the ocean floor.
(Photo courtesy of National Science Foundation)

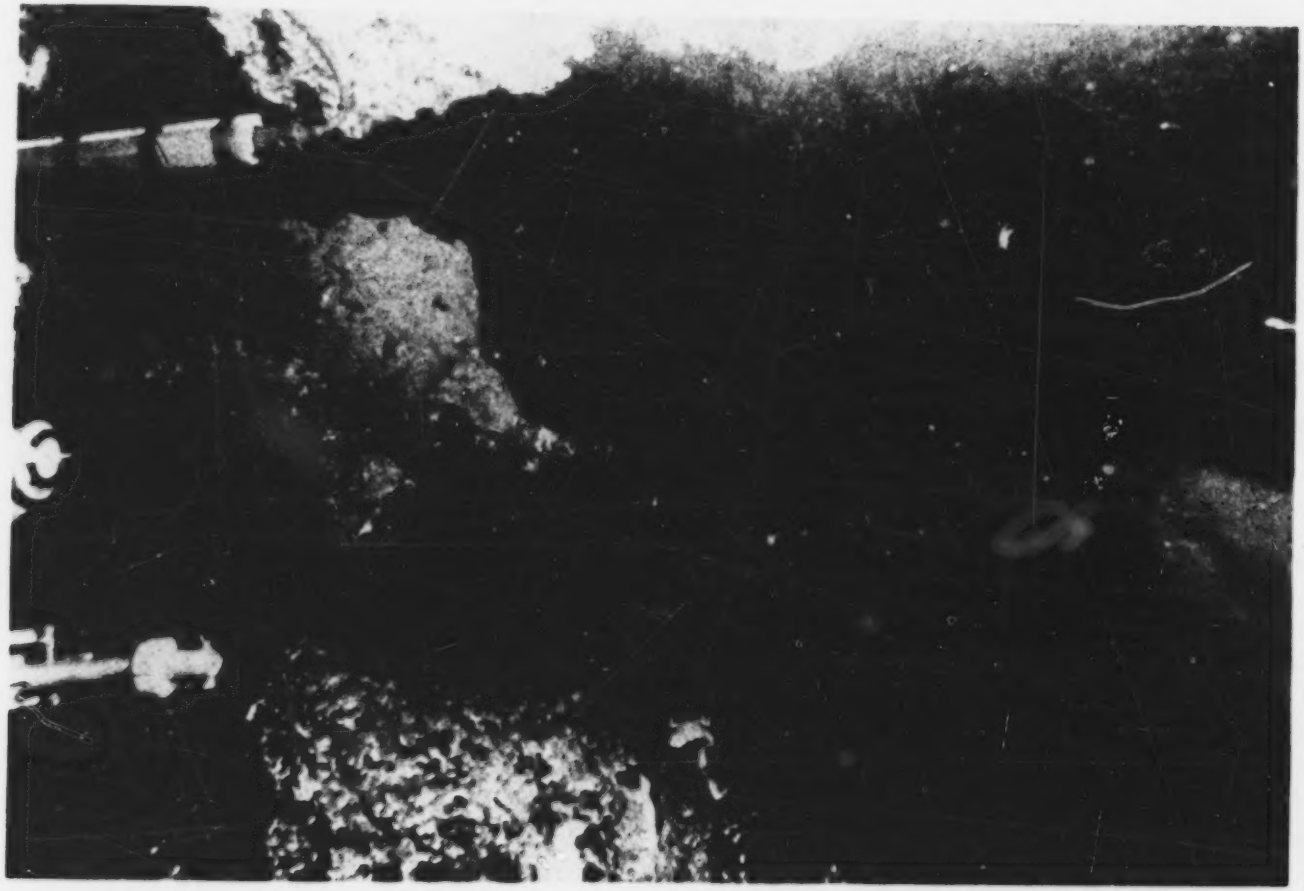

Plate 3. (Photo courtesy of National Science Foundation)

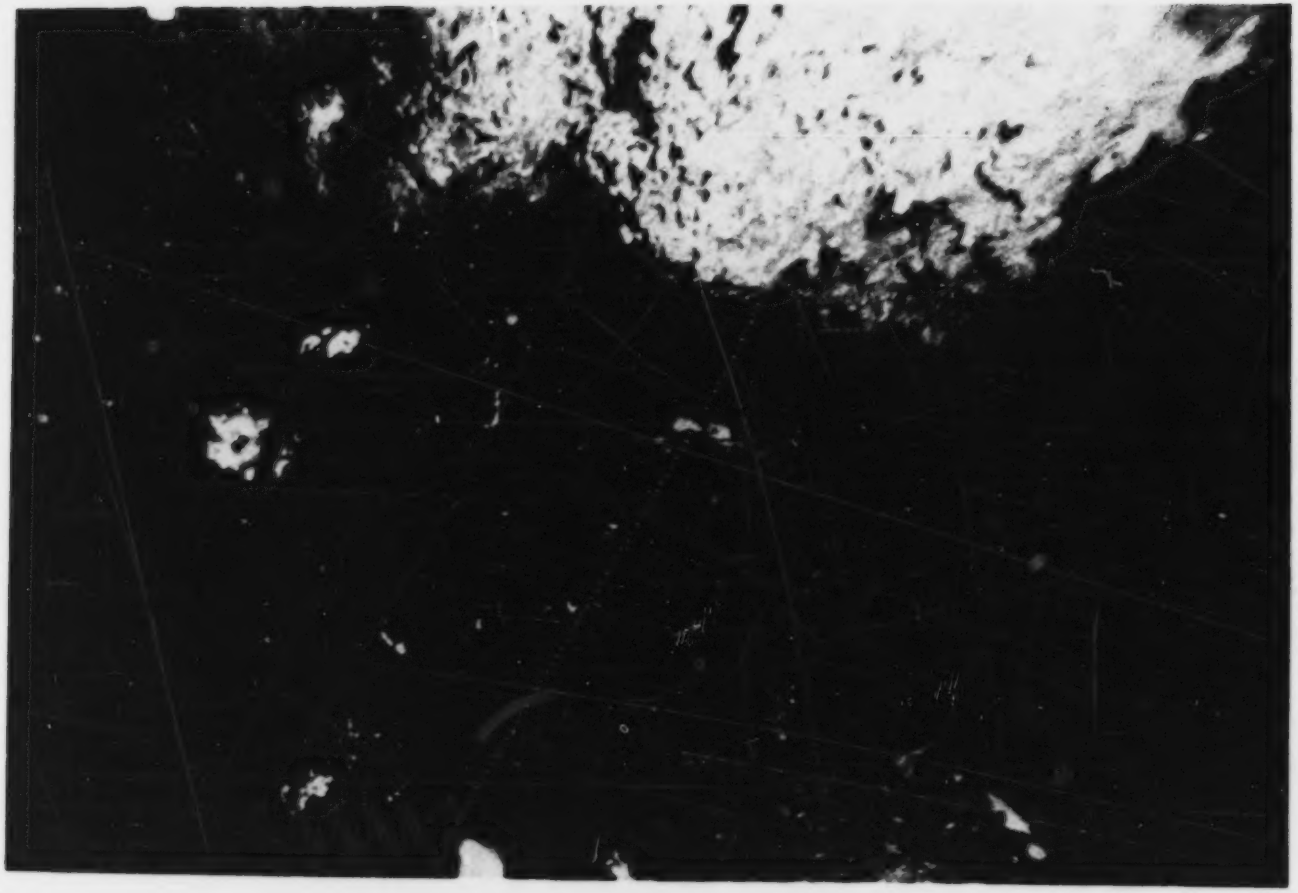

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Plate 4, 5, 6, and 7. Unusual biota found in vent areas showing large tubeworms, crabs, and giant clams.
(Photo courtesy of National Science Foundation)

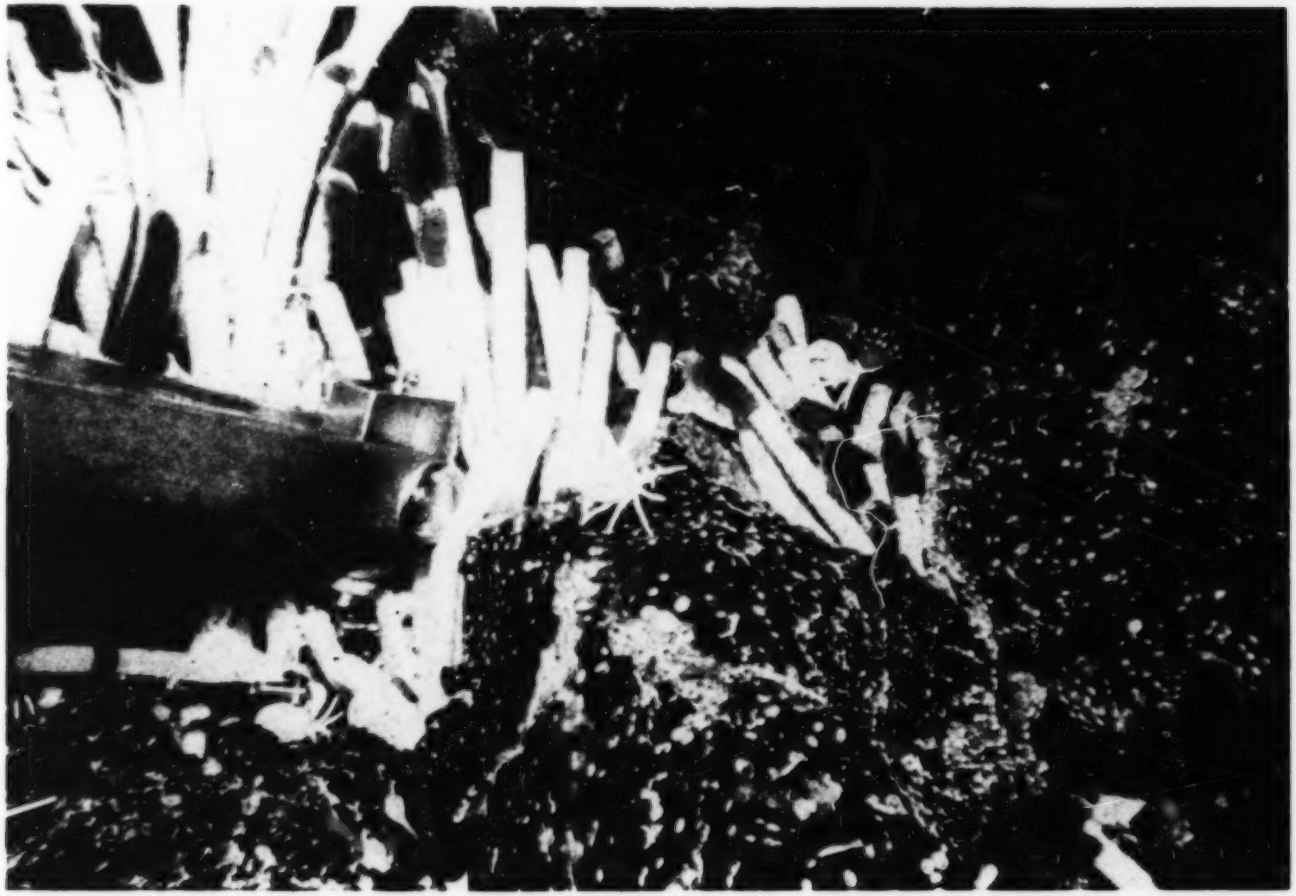

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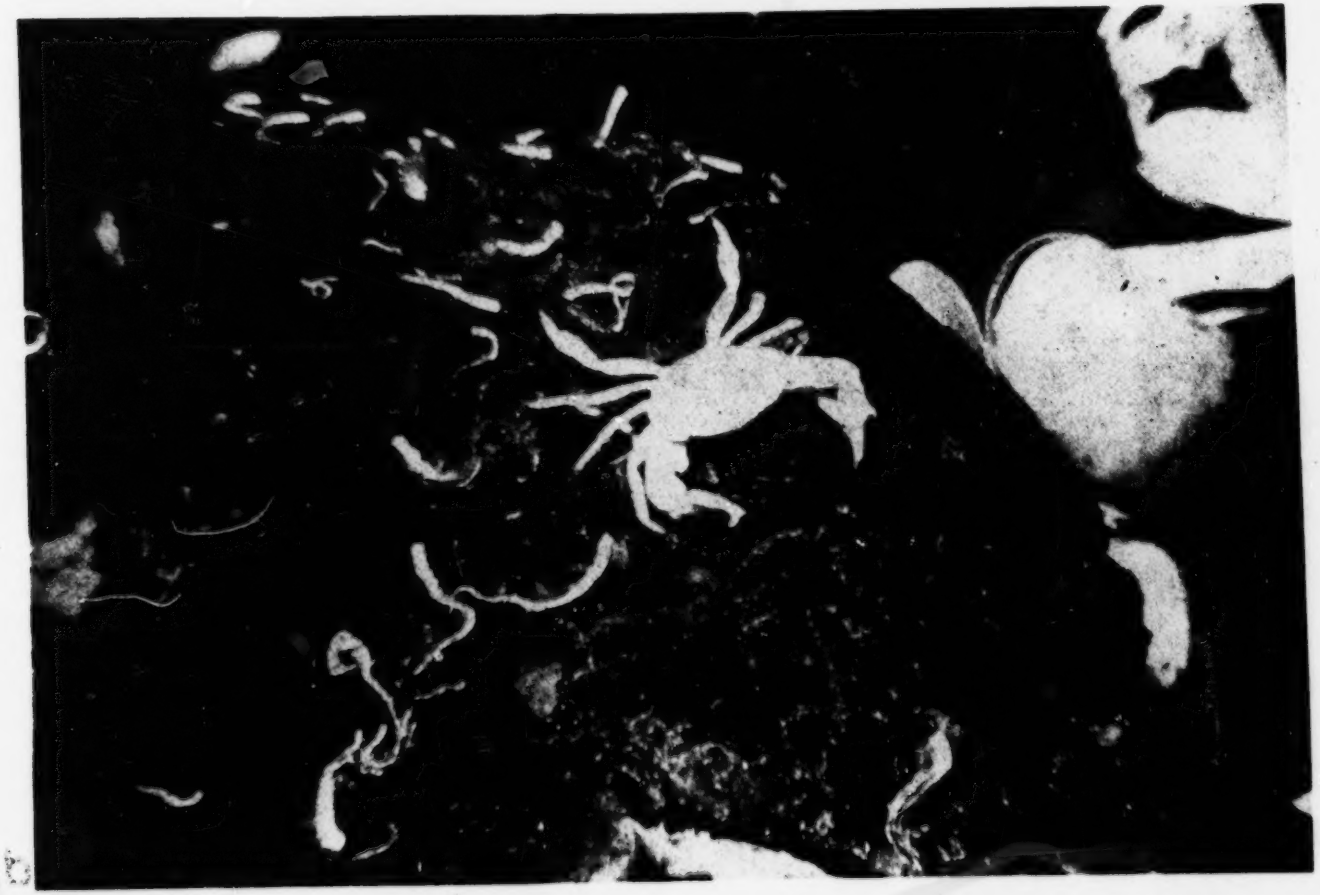
Plate 5. (Photo courtesy of National Science Foundation)



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sunlight as an energy source the biota thrive. Scientists are studying the adaptions these animals have made in order to survive these extremes.

Most animal communities depend on plants to use energy from the sun to synthesize carbohydrates and furnish food. The vent biota ultimately derive their energy from the hydrothermal process which produces sulfur compounds. Bacteria use the energy stored in the sulfur compounds, hydrogen sulfide, in combination with carbon dioxide and oxygen to synthesize proteins and other organic compounds. The bacteria use the energy from sulfur compounds the way plants use solar energy. The sulfur digesting bacteria thrive in the hot briny water spewing from the stacks and chimneys. The bacteria are found growing in the vent waters, as dense mats surrounding the vents, and in the bodies of clams and tube worms. The tube worms are large (four to six feet in length), mouthless and gutless, which flourish in dense colonies near the vents. They have blood-red tips of bundled tenacles which contain hemoglobin. They can contract into their tube homes which are composed of a tough but flexible organic material. The worms often anchor on warm rock but their bodies extend into cold water; they must be adapted to a temperature range along the length of their bodies. The clusters of white-bodied, red-tipped worms make a spectacular picture when illuminated in the darkenss of the vents.

The mussels are typically found at a distance from the vents, those farther away being smaller due to reduction in the food source. The clams are found even farther away from the vents in even cooler water.

Crabs and fish move in and out of the vents, presumably for feeding purposes, climbing or swimming over the bivalves and through the colonies

of tube worms. Films of the vent communities portray a lively, colorful, thriving biological community in the midst of pillars of smokey water.

Although the uniqueness of these organisms is the subject of considerable study, a detailed discussion is not appropriate here. A list of several curious characteristics follows to illustrate some of the unusual adaptations that have been observed.

1. The crabs dart from near freezing temperature water into the hot vents to feed and out again unharmed. Their blood is capable of transporting large quantities of oxygen whether its temperature is 36 or 86 degrees Fahrenheit.

2. Giant tube worms, minus mouth and digestive system, house the sulfur digesting bacteria and directly absorb carbohydrates and proteins manufactured by the bacteria.

3. Small shrimp-like crustaceans have comb-like structures at the end of their eye stalks where eyes would normally be. The combs, never before observed in crustaceans, are thought to be used to scrape food (microorganisms) from hard surfaces.

4. Some of the organisms seem to have an unusually rapid growth rate which may be adaptation to habitats that may last only a few decades.

5. Although there is no light, some of the organisms are brilliantly colored such as the blood-red plumes of the tube worms. 9/ 10/ 11/ 12/ 13/

9/ Harney, Thomas. Giant Tube Worms: A Mystery Solved. Smithsonian Institution Research Reports, no. 34, Autumn 1981.

10/ Rhodes, D. et al. Growth of Bivalves at Deep-Sea Hydrothermal Vents Along Galapagos Rift. Science, vol. 214, Nov. 20, 1981, p. 911-912.

11/ Galapagos Expedition Participants. Galapagos 79: Initial Findings of a Deep Sea Biological Quest. Oceanus, vol. 22, no. 2, Summer 1979, p. 2-10.

12/ Sullivan, Walter. New York Times, Apr. 24, 1982, p. 1 and 7.

13/ Hiatt, Blanchard. Sulfides Instead of Sunlight. Mosaic, July/Aug. 1980, p. 15-21.

III. RESEARCH AND DEVELOPMENT

The research related to marine hydrothermal vents is one of the most important areas of oceanographic research today. In the last 20 years, technological developments in areas such as sonar mapping, deep ocean photography, and submersible research vessels have opened up a new world of the deep ocean floor for exploration. The research made possible by these advancements had led to new ideas concerning such things as sea floor spreading, ocean water circulation and chemistry, and generation of mineral deposits (which applies to land-based as well as deep ocean mineral formations). Perhaps the most surprising finding, and one that best illustrates the frontier nature of the ocean is the discovery of the exotic animal communities associated with the hydrothermal vents.

This history of the research and exciting recent discoveries exemplify not only the vastness of the oceans' unknown but also illustrates many important aspects of the development of modern oceanographic research such as: 1) evolution of a truly multi-disciplianry field of science; 2) coordination and cooperation of a variety of government and academic groups; 3) international cooperation and support, often involving multi-national research projects; and 4) use of expensive and sensitive facilities. Examination of these aspects of oceanographic research gives some insight into several of the issues that are present and to some that may arise in conjunction with possible development of the ocean resources.

RESEARCH HISTORY AND VENT DISCOVERY

Beginning in the 1960's a significant amount of ocean research was focused on seafloor spreading centers or ridges. Scientists looked at the composition of the rocks and seawater, the nature of heat flow from within the earth, and the structure and topography of the ridges. Heat flow anomalies, metal rich sediments, basaltic rocks altered by seawater, and helium anomalies were found to be associated with the ridge crests. By the early 1970's there was significant evidence that hydrothermal circulation of oceanic water was an important process at the ridge crests. 14/

14/ Malfait, Bruce. Hydrothermal Vents. National Science Foundation Program Report, vol. 4, no. 3, May 1980.

1974 marks the beginning of a new and very active period of ocean spreading center/ridge exploration and research. In 1974, the Project FAMOUS (French American Mid-Ocean Undersea Study) program was undertaken on the Mid-Atlantic Ridge (centered around 36 degrees 50 minutes N, southwest of the Azores Islands). FAMOUS was a cooperative project between French and American scientists, supported by the National Science Foundation (NSF), Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA). In addition to detailed shipboard geophysical work, three deep-sea submersibles, the French Archimede and Cyana and the American Alvin, dove into the rift valley many times to map and collect samples. One objective of the project was to find hydrothermal vents in the ridge; none were located but the project identified that the central volcanic zone of the

mid-Atlantic ridge was fractured implying that the least the upper portion of the crust was permeable enough for circulation of seawater. 15/ 16/

15/ Ibid., p. 10.

16/ Press, Frank and Raymond Siever. Earth. San Francisco, W.H. Freeman and Company, 1974, p. 261.

The FAMOUS project demonstrated the scientific importance of a direct observation of the ocean bottom by scientists in deep diving manned submersibles. The Alvin, operated by Woods Hole Oceanographic Institution, has the capability to dive to depths of thousands of feet, to sample and photograph the ocean floor (see section on DSRVs). The Alvin and vehicles like it have been crucial in the exploration of the hydrothermal vents.

In 1977, the Galapagos Project (86 degrees W) a multi-investigator project, was directly aimed at locating, sampling and characterizing the chemistry of hydrothermal fluids. Fields of hot springs were discovered at depths of 8,000 feet and four vents were sampled. Work on the chemical composition showed the vent waters to be seawater that had reacted with hot basalt and mixed with cold ocean water. Many important ideas came out of this work including: mechanisms for water circulation and mixing, volume and time of seawater circulation, and heat flux values. 17/

17/ Edmond, J.M. Hydrothermal Activity at Mid-Ocean Ridge Axes. Nature, v. 290, Mar. 12, 1981, p. 87.

A group of scientists from France, Mexico and the United States, gathered in 1976 to discuss the mid-ocean ridge work and plan a direction for further research. They were interested in exploring ridges with faster spreading rates than those found in the mid-Atlantic. The question was, where to go next. The Galapagos had had some exploratory work done; the decision was made to concentrate on the East Pacific Rise (EPR) at 21 degrees N (south of the mouth of the Gulf of California). The discussion also focused on ways in which newly available capabilities for detailed studies of the sea floor, particularly manned submersibles, might best be further developed and used in the Pacific Ocean. Several cruises, directed toward detailed geological and geophysical investigation of the EPR crest, came from this meeting: the Rivera Submersible Experiments (RISE); and the CYAMEX program.

In February-March of 1978 the French-American-Mexican expedition, CYAMEX, explored and sampled "ore-grade deposits of zinc, copper and iron sulfide" using the manned diving saucer CYANA. The expedition was the first of its kind at the axis of the East Pacific Rise. The CYAMEX scientists compared the EPR deposits with a modern analogue: the Cyprus-type sulfide ores associated with ophiolitic rocks (rocks rich in dark-colored, ferromagnesian minerals) on land. The deposits contain as much as 30 percent zinc and six percent copper. 18/

18/ Francheteau, J., et al. Massive Deep-Sea Sulphide Ore Deposits Discovered on the East Pacific Rise. Nature, v. 277, Feb. 15, 1979, p. 523.

The principal technical aspect of the RISE project which differed from the FAMOUS and Galapagos projects was an effort to develop and exploit

geophysical measurement capabilities which the submersibles did not possess at that time. Prototype geophysical experiments were conducted in the vent area on the East Pacific Rise (EPR) at 21 degrees N in 1979. Using the Alvin and tender Lulu from Woods Hole Oceanographic Institute (WHOI), a deep tow system from Scripps Institution of Oceanography, and the ANGUS camera sled (with temperature sensors) from WHOI, the RISE group discovered actively discharging hydrothermal vents, forming sulfide mineral deposits. Another exciting discovery was the observation of exotic benthic communities similar to those found previously at the Galapagos spreading center. 19/ 20/

19/ RISE Project Group. East Pacific Rise: Hot Springs and Geophysical Experiments. Science, v. 207, Mar. 28, 1981. p. 1421.

20/ The French renamed the joint effort, the RITA Project, because the study area is located between the Rivera and Tamayo transform faults. This name is not generally accepted by the U.S. scientists involved in the project; they have kept the original designation of RISE.

In parallel with the discoveries made at Galapagos and EPR 21 degrees N in 1977, U.S. scientists from Scripps, found evidence of active springs in the area of the Guaymas Basin in the northern part of the Gulf of California. This part of the ridge axis is buried under several hundred feet of sediments. In 1980, a Deep Tow survey yielded photographs of active hot springs. Sulfide minerals were recovered by dredging.

In addition to the polymetallic sulfides and unusual marine biota, the area houses another attraction-petroleum. The most remarkable of the biota are the carpets of filamentous bacteria- so large they are visible to the

naked eye. An expedition of scientists from Scripps returned in January of 1982 with the news of a natural "oil refinery" in the basin. 21/

21/ Sullivan, Walter. Divers Find Natural 'Oil Refineries'. New York Times. Jan. 29, 1982.

A joint U.S.-French program, in 1980, using SEABEAM--a high resolution bathy-metric mapping array and the RAIE towed camera system found active sulfide deposition at several locations on the East Pacific Rise. Numerous samples were obtained by dredging. 22/

22/ Edmond, Hydrothermal Activity at Mid-Ocean Ridge Axes, p. 88.

In 1980, scientists from the U.S.G.S. and the University of Washington, Seattle did exploratory work on the Juan de Fuca Ridge. The research included geophysical studies, deep tow camera work, and preliminary geochemical and magnetic studies. This cruise and the detailed maps compiled by NOAA with the use of the SEABEAM system, provided the ground work for another cruise to the area in 1981.

NOAA scientists returned from the Galapagos Ridge in 1981 with several hundred pounds of polymetallic sulfides. They located, mapped and sampled the most massive polymetallic sulfide deposit found to date, thought to be 100 feet thick, 600 feet wide and 3,000 long. Using the NOAA research vessel specially equipped with the SEABEAM system and the Alvin, researchers saw and photographed "chimneys" of sulfides along marginal ridge faults. The discovery was met with much attention, in part, due to the implications for economic

potential of the deposits and possibility of similar deposits in geologically related spreading centers, some within 200 miles of the U.S. coast. 23/

23/ Personal Comm. Alex Malahoff NOAA Ocean Minerals and Energy. Feb. 1982.

The U.S.G.S./University of Washington cruise in September of 1981 proved to be very productive when scientists located and photographed six vents on the southern Juan de Fuca Ridge, dredged sulfide samples from 7,000 feet depth and confirmed the projections of many scientists as to the likelihood of polymetallic sulfide mineralization in the area. The massive sulfide is more than 50 percent lead with significant amounts of silver, cadmium, and copper. 24/

24/ Personal Comm. Randolph Koski, U.S.G.S Pacific-Arctic Branch of Marine Geology, Feb. 1982.

Extensive plans for research are being made for the East Pacific Rise spreading centers by groups in government and academia. Further research will most likely include efforts directed toward: identifying the processes involved in generation of the sulfide deposits; and means to locate and define the extent of the resource (such as sophistication of sonar mapping systems to distinguish rock types).

Although this research effort has greatly expanded our knowledge of earth processes and it is, in many ways a landmark in oceanographic research, it is not without problems. Scientists from the U.S. and other countries have pooled their expertise, research funds, equipment, vessels, and data for a number of studies but in some cases, disagreement and lack of communication

have resulted in a lack of cooperation that has been detrimental to the effort as a whole. There have been disagreements over: government agency responsibility, availability of data, locations for studies, types of experiments to be conducted, and appropriate levels of funding.

In addition, there is a case, in which a project had to be changed because permission for research within foreign waters was not granted. As the interest grows, from both a scientific and economic perspective, and research moneys become more scarce, some of the existing problems may become more pronounced.

This discussion is, by no means, intended to be a comprehensive or exhaustive treatment of the research efforts that have contributed to our knowledge of hydrothermal vents and mineralization. But rather, it is an illustration of the breadth of interest and contributions from scientists throughout the U.S. and a glimpse of the multi-national cooperation. A complete list of researchers would, no doubt, be unmanageable and, considering the wide range of scientific disciplines involved, be growing constantly. Of greater importance is the recognition of the variety and number of groups involved and the benefits and drawbacks that may arise from this historic thrust in scientific research. The following is a list of governmental agencies, private institutions, and foreign countries that have been or are actively involved in the research.

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Plate 6. (Photo courtesy of National Science Foundation)

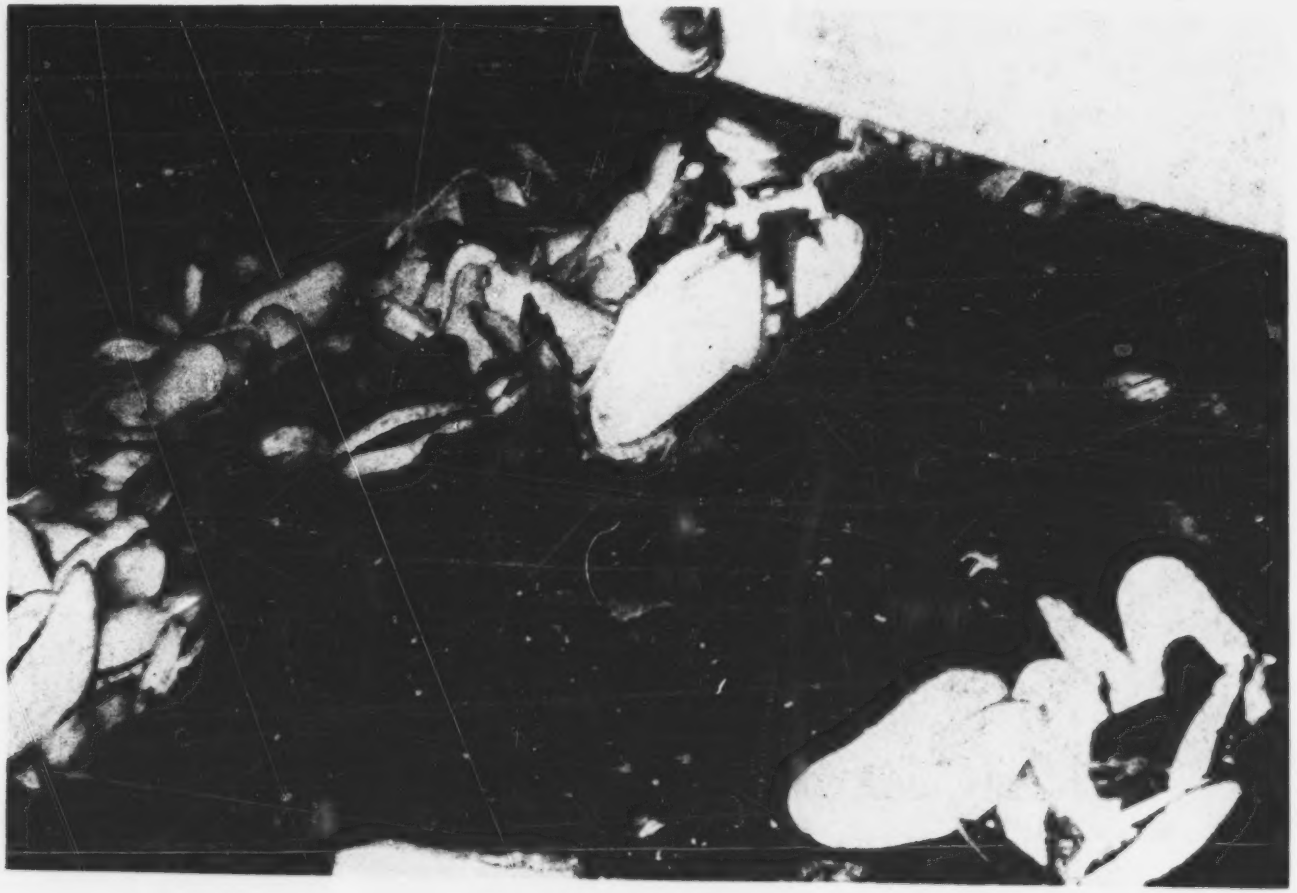

Plate 7. (Photo courtesy of National Science Foundation)

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LIST OF PARTICIPANTS

The United States has played an active role in the advancement of research related to hydrothermal vents. Examples of the groups that have been actively involved follows.

Federal Government

a. United States Geological Survey (U.S.G.S.)
   Office of Marine Geology

b. National Oceanographic and Atmospheric Administration (NOAA)
   Sea Grant Program (Funding academic research)
   National Ocean Survey
   Office of Ocean Minerals and Energy

c. National Science Foundation (Funding academic research)

Private Organizations

Harvard University

Lamont-Doherty Geological Observatory

Massachusetts Institute of Technology

Oregon State University

Scripps Institute of Oceanography

State University of New York

Stanford University

University of California

University of Oregon

University of Washington

Woods Hole Oceanographic Institution

Foreign Efforts

Canada

France

Germany

Japan

Mexico

RESEARCH TECHNOLOGY DEVELOPMENT

Exploration of the deep ocean floor has demanded refinement and adaption of several existing research tools as well as the creation of new technology. Advancements in research technology have occurred in the use of echo-sounding techniques for mapping, additions to the DSRV's for photography and sampling, and adaption of sonar and camera equipment for deep-tow data gathering. The advancements in technology have been crucial for deep ocean research and have opened several windows in a part of the world that was relatively inaccessible.

Sea Floor Mapping

Sonar Systems

Major advances in ship-based echo-sounding techniques have overcome the problem heretofore of extremely restricted resolution in ocean floor observational tools. Conventional surface ship bathymetric mapping yields

very little information at horizontal scales less than a few hundred meters when mapping in rough terrain such as the spreading ridge areas. Thus, optical devices and geophysical sensors were operated without detailed bathymetric maps which requires that they be towed at some distance from the sea floor and very slowly to avoid contact with the bottom. The more precise sounding techniques have allowed for not only identification of finer scale features from the bathymetric maps, but also closer (less hazardous) observation with the towed equipment and DSRV's. 25/

25/ Edmonds, J.M. Ridge Crest Hot Springs: The Story So Far. EOS, v. 61, no. 12, Mar. 18, 1980, p. 129-131.

The U.S. Navy has, for a number of years, used the Sonar Array Survey System (SASS) to map sections of the ocean floor. SEABEAM, the civilian version, is a multibeam echo sounding system of resolving features on the ocean floor that may be as small as 65 feet in length and 16 feet in height at water depths of 12,000 feet (figures III-1, III-2, and III-3). The system produces real time contour strip charts as well as digital output to a data logger or magnetic tape recorder. The SEABEAM has been used on the French ship, Jean Charcot, since 1977 and the NOAA ship, Surveyor, since 1980 (dry docked in the fall of 1981). 26/ 27/

26/ Malahoff, Alex. Comparison Between Galapagos and Gorda Spreading Centers, Offshore Technology Conference. Houston, Texas, May 1981.

27/ SEABEAM, General Instrument Corporation, Harris A.S.W. Division

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Deep-Towed Systems

Deep-towed instruments flown (towed) 10 to 200 meters from the seafloor have played a crucial role in seafloor exploration. One such system maintained at the Marine Physical Laboratory at Scripps has been gathering fine scale survey data since 1960. Included in the capabilities of the Scripps deep-towed instrumentation system are:

1. Navigation using recoverable seafloor acoustic transponders. Ranges to 15 km, uncertainties of of 5 meters.

2. Echo-sounding using a combination of up and down-looking units (down system with 4° beamwidth) to give total water depth to an accuracy of 2 to 3 m in total water depths to 7000 m.

3. Proton precession magnetometer with repetition interval controllable from 10 sec. up.

4. Side-looking sonar (one channel each side) with 3/4° horizontal beamwidth.

5. Bottom penetration sonar giving resolution of internal reflectors to greater than 50 m depth in sediment.

6. Conventional stereo (55° field of view) and wide-angle (90° field) photo system using a 200 watt-second strobe capable of obtaining clear pictures in deep ocean water at camera heights of 12 m off bottom.

7. Precision temperature measuring system - resolution to 0.001° C.

8. Snapshot television using strobe flash illumination and half-second scanning time for narrow band telemetry. 28/

28/ Spiess, F.N. and R.C. Tyce. Marine Physical Laboratory Deep-Tow Instrument System, sponsored by the Office of Naval Research and the National Science Foundation, Summary, Mar. 1973.

In addition to making significant contributions alone, deep-towed systems have provided the base data such as detailed bathymetric profiles, side scan sonar records, and bottom photographs for further work with other deep sea research systems.

Camera Systems

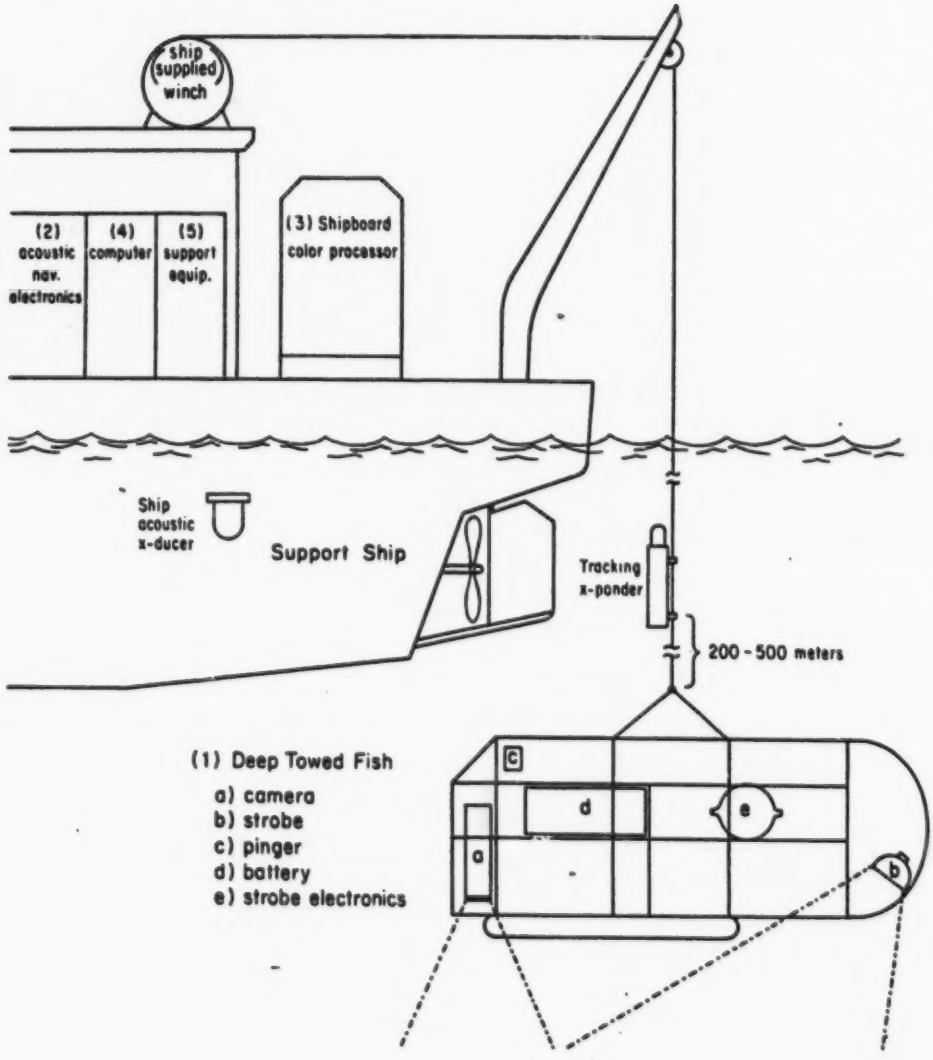
A crucial addition to the seafloor exploration technology was development of an advanced towed camera system, equipped with color cameras, strobes, power supplies, and acoustic navigation transponders to refine and gather more information on the features located by means of detailed mapping. The ANGUS (Acoustically Navigated Geological Underwater Survey) system managed by Woods Hole Oceanographic Institution (WHOI), grew out of an engineering development effort administered the Office of Naval Research (figure III-4). ANGUS, fitted with "super strobes" can be flown relatively rapidly 65 or 100 feet off the bottom, taking photographs of an area 100 feet square. The system has the capability to take pictures every ten seconds for an 18-hour period. With the use of ANGUS or other camera systems of this nature (plate 8), it is now possible to conduct precisely navigated photographic travers across the seafloor. ANGUS, a remote observational system, is a follow up or complement to detailed geophysical mapping and a precursor to more direct human observation from the use of Deep Submergence Research Vehicles (DSRVs).

Deep Submergence Research Vehicles (DSRVs)

The manned submersibles enable scientists to venture to great depths for direct observation, data acquisition, and sampling. The Alvin, owned

Figure III-4.

ANGUS SYSTEM



Source: Woods Hole Oceanographic Institution

Plate 8. Camera system used by the University of Washington to photograph the Juan de Fuca Ridge in 1980 and 1981.
(Photo courtesy of Sally Frodge, Univ. of Washington)

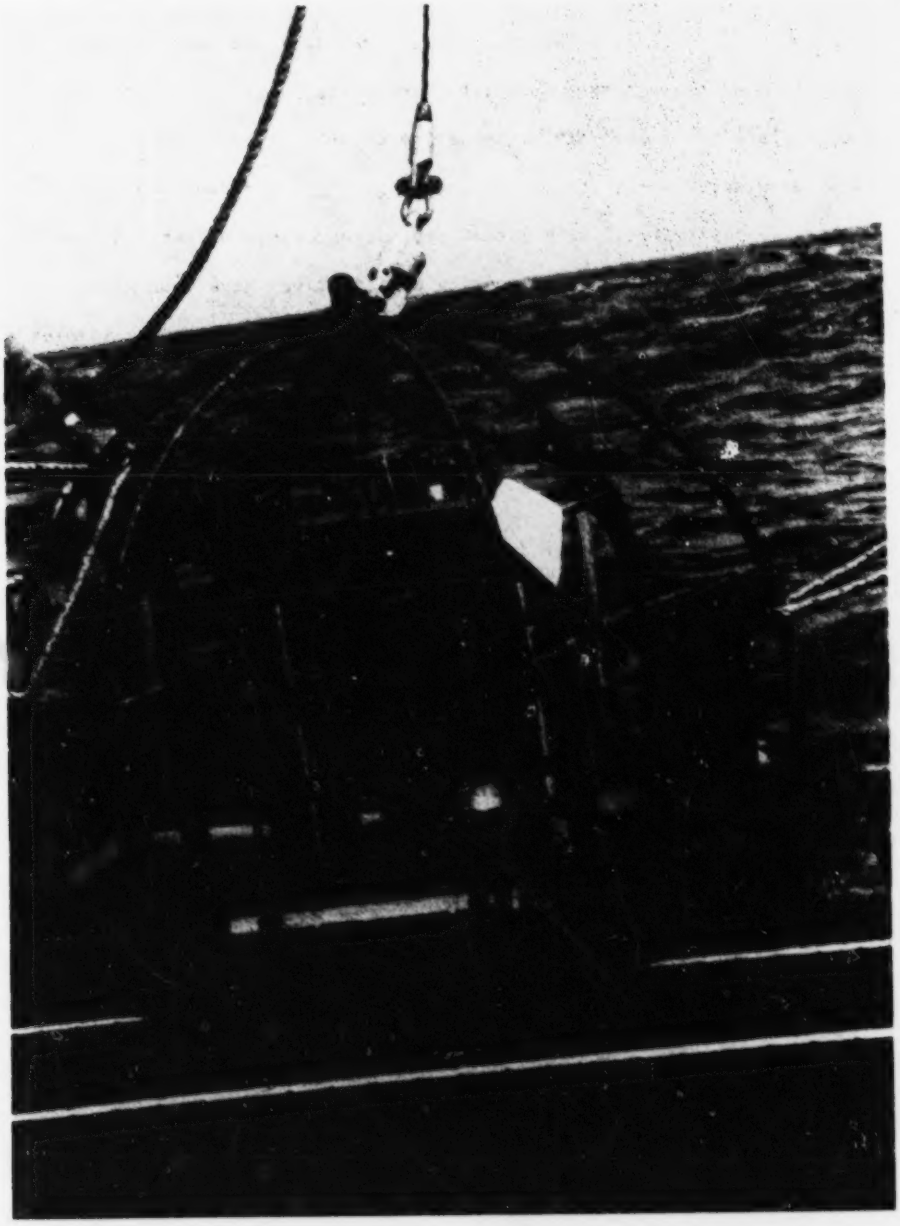


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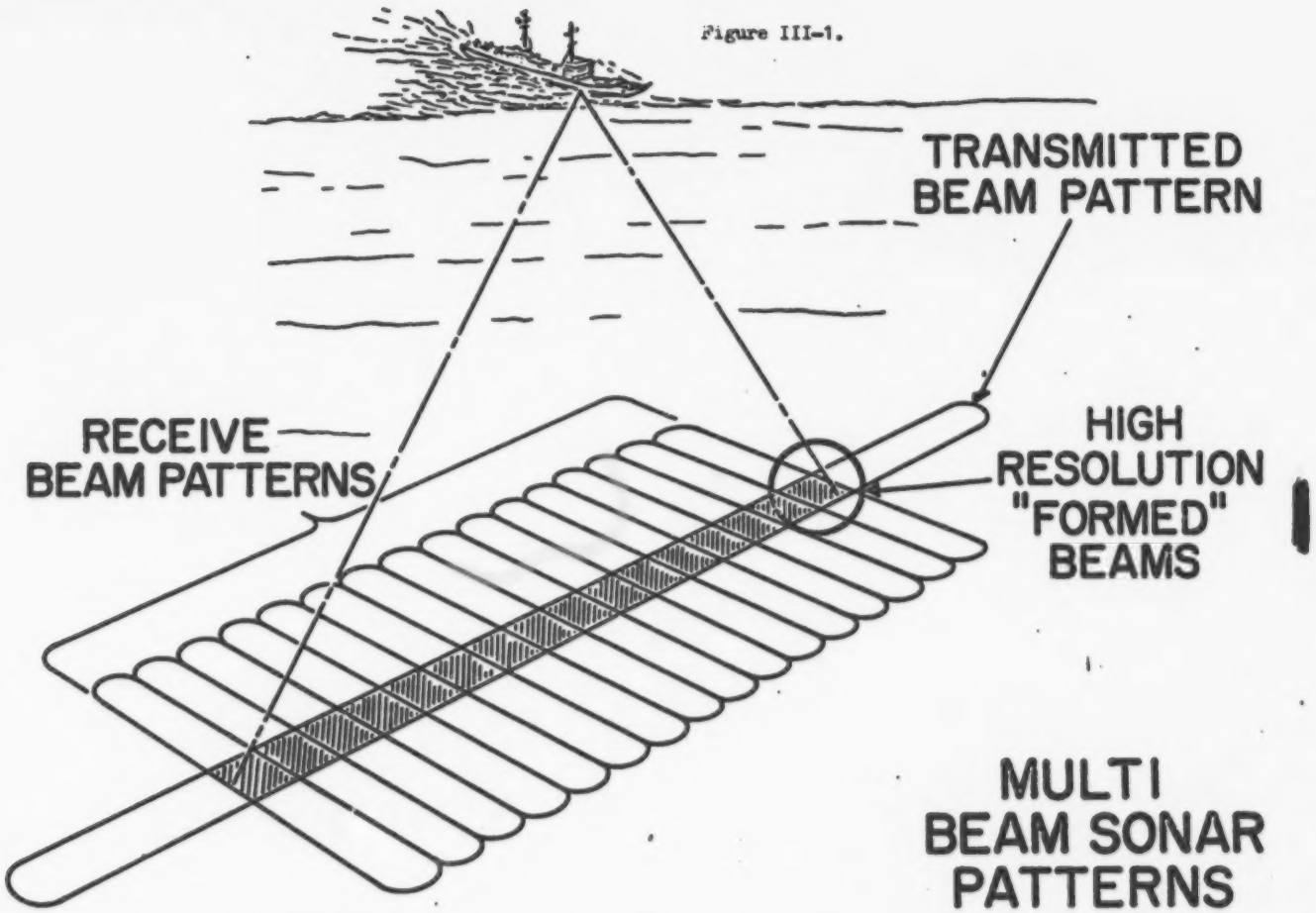
Figure III-1.



Source: General Instrument Corporation, Harris A.S.W. Division

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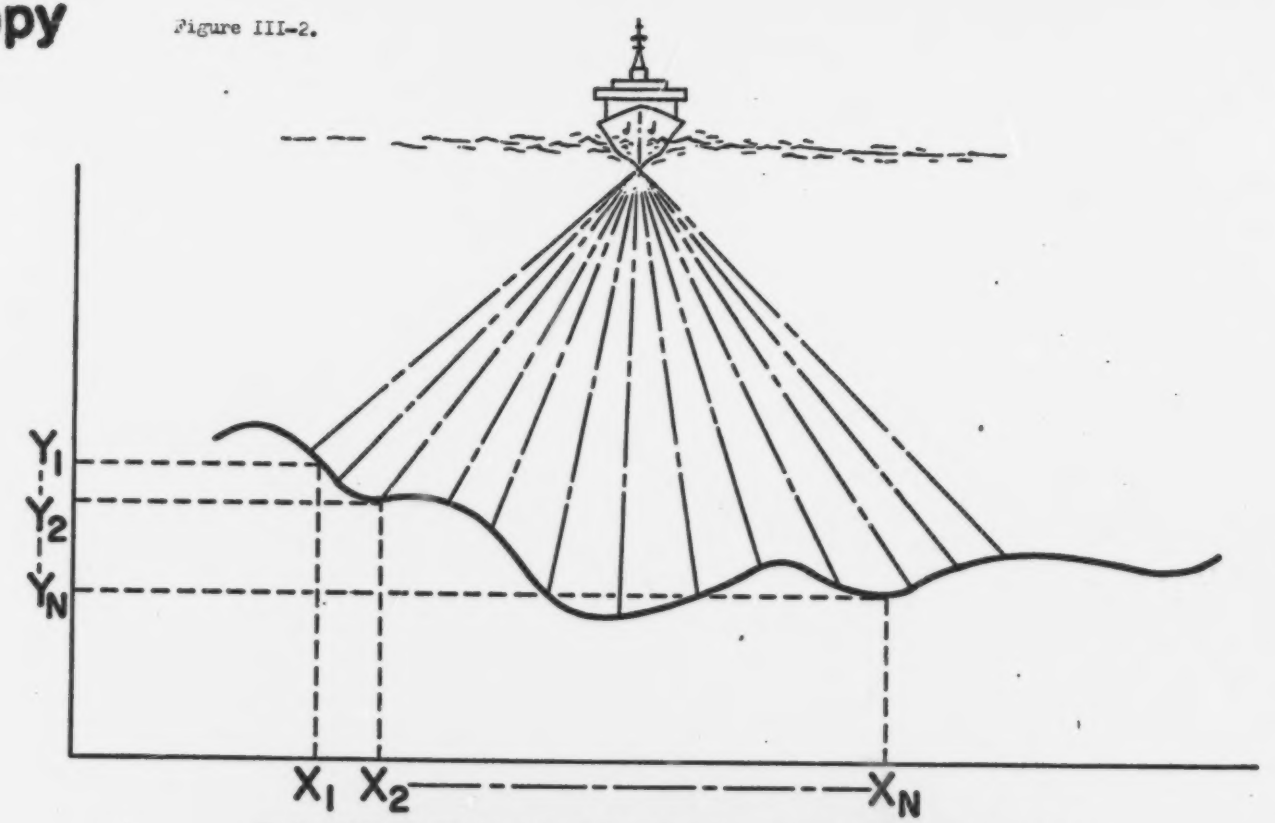
Figure III-2.



PAIRS OF X-Y BOTTOM COORDINATES
ON EACH PING ARE OBTAINED
AND USED TO GENERATE CONTOURS

Source: General Instrument Corporation, Harris A.S.W. Division

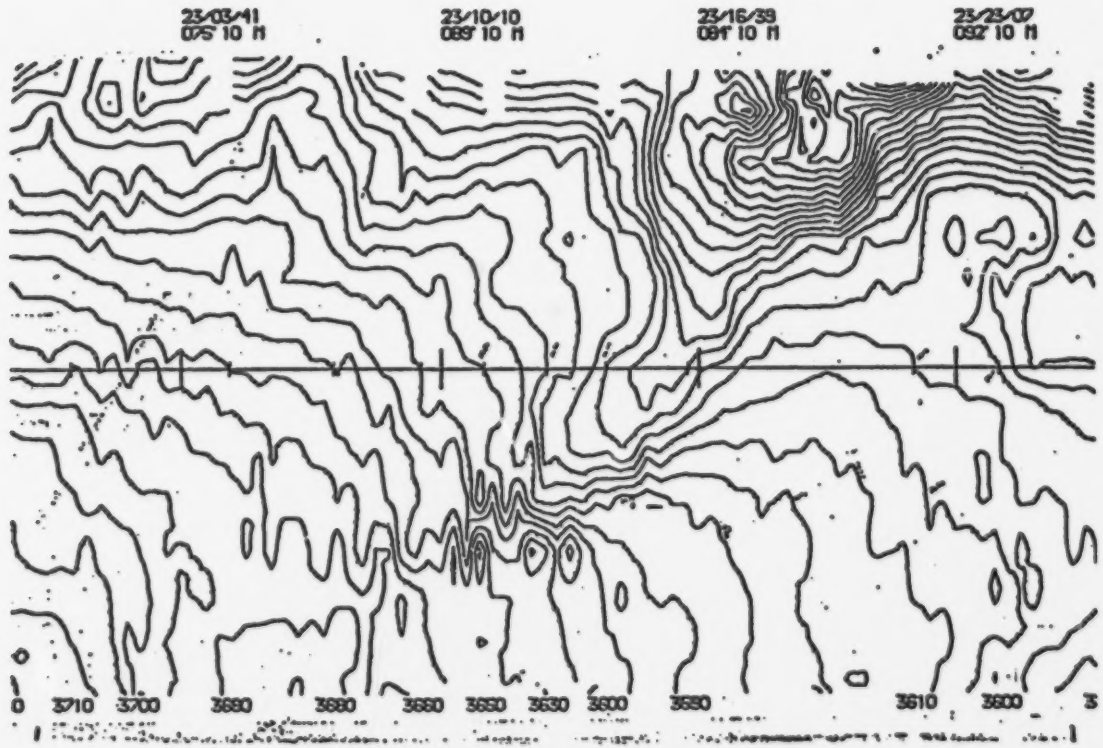


Figure III-3. SEABEAM STRIPCHART

REALTIME BOTTOM CONTOUR STRIPCHART (10 METER CONTOURS) PRODUCED ABOARD THE FRENCH OCEANOGRAPHIC SHIP "JEAN CHARCOT" OF THE CNEXO FLEET ON MAY 26, 1977.

Source: General Instrument Corporation, Harris A.U.W. Division

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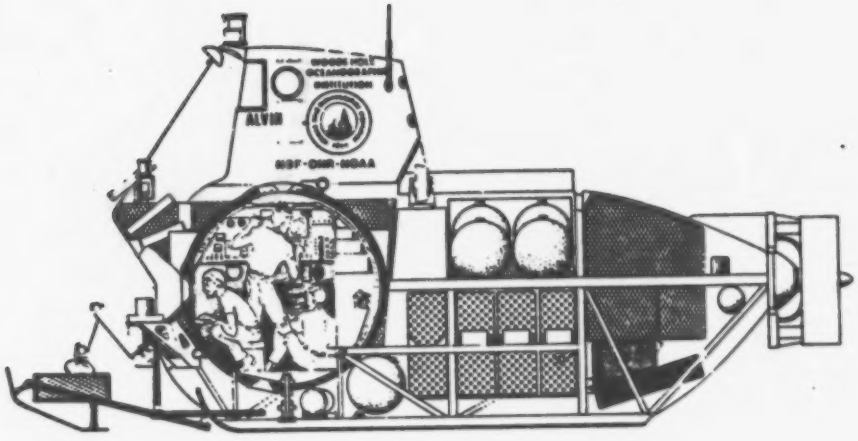
by the Office of Naval Research and operated by Woods Hole Oceanographic Institution with support from the National Science Foundation, NOAA, and the Office of Naval Research, is an example of such a vessel and has been used extensively in hydrothermal vent research. The Alvin program was initiated in 1961 with plans for a deep-diving submarine capable of participating in programs of underwater acoustics, ocean bottom geology, and deep sea biology. By 1965 Alvin was operational with manned deep dives of 6,000 feet. Subsequently, a number of design and engineering modifications have been made. Now Alvin routinely conducts dives to 8,000 to 10,000 feet collecting samples of water, biota, and rocks, with two remotely controlled collecting arms, measuring temperatures, and taking photographs with external camera equipment (figure III-5, plates 9 and 10). 29/

29/ Sharp, Arnold G. and Lawrence A. Shumaker. DSRV Alvin: A Review of Accomplishments Woods Hole Oceanographic Institution Technical Report, Jan. 1977.

It is a three man submersible, titanium hull capable of sustaining 50,000 tons of pressure per square inch. Alvin can remain submerged and mobile for 12 hours which, in an emergency, could be extended to 36 hours. Diving time is approximately 90 minutes to 8,500 feet. 30/

30/ Barrows, Jean. Polymetallic Sulfides: Frontiers on Ocean Mineral Exploration. Annual meeting of the Association of American Geographers. Apr. 26, 1982.

FIGURE III-5. DSRV Alvin



Source: Woods Hole Oceanographic Institution.

IV. POTENTIAL ECONOMIC SIGNIFICANCE

POTENTIAL METALS RECOVERY

At the present time too little is known of marine polymetallic sulfide deposits to project their economic significance beyond general expectation of future potential. The possible dimensions of that future potential, however, are beginning to attract some interest. No systematic surveys of the volume and grade of any of the deposits have been undertaken. Consequently, on the basis of current data it would not be considered prudent to extrapolate indicated dimensions and grade of the known deposits to derive uncertain dollar values. However, some degree of speculation may be justified. Analyses of grab samples of sulfides collected from several spreading zones indicate highly variable metal values, particularly from one zone to another. Typical weight percentage ranges of some metals found in the massive sulfide deposits are given in table IV-1. Some of the higher analyses are from individual samples composed almost entirely of one or two metal sulfide minerals and analyze much higher in those metal values, e.g., the Juan de Fuca Ridge sample which is 54 percent zinc, primarily sphalerite and wurtzite (zinc sulfide). In any event, it is certain that any future mining of hydrothermal deposits would recover a number of metal coproducts.

TABLE IV-1. Preliminary Analyses of Polymetallic Sulfides Showing Weight Percentages of Metals Found.

Metal	Percent by Weight
Copper	0.3 - 10.0
Silver	0.001 - 0.04
Zinc	0.1 - 54.0
Lead	0.1 - 0.35
Manganese	0.03 - 0.3
Molybdenum	0.01 - 0.1
Vanadium	0.01 - 0.1
Iron	greater than 10

Source: Data from material made available by Alexander Malahoff, National Ocean Survey, NOAA and N. Terrence Edgar, Office of Marine Geology, USGS.

Despite the highly speculative nature of assigning tonnages and dollar values to ocean polymetallic sulfide occurrances, some such values have begun to appear (tables IV-2 and IV-3). A great measure of caution should be exercised in evaluating data related to these deposits. The deposits have only been examined from a scientific perspective related primarily to the process of hydrothermal circulation and its chemical and biological influence on the ocean. No detailed economic evaluation of these deposits or potential recovery techniques have been made.

TABLE IV-2. Value Estimates of the Polymetallic Sulfide Deposit Near Galapagos Island

Metal	Value $/Unit*	%Reported	Gross $Value - 10^9 (**)	Estimated Recoverable (***)	$Value
Copper	0.86/lb	10.0	4.3×10^9	60%	2.6×10^9
Silver	8.92/tr oz.	0.3	1.8×10^9	60%	9.8×10^8
Cadmium	1.8/lb	0.01	9	-	-
Iron	80/lt	10.0	0.2	-	-
Molybdenum	8.75/lb	0.1	437	60%	2.6×10^8
Lead	0.4/lb	0.1	22	-	-
Tin	7.5/lb	0.03	113	-	-
Vanadium	2.0/lb	0.1	98	60%	5.9×10^7
Zinc	0.5/lb	0.1	24	-	-
					3.88×10^9
				Value/Ton	$155.20

* Engineering & Mining Journal, September 1981.
** 25 Million tons assumed.
*** Arbitrary assumption.

TABLE IV-3. Estimated Volumes of Polymetallic Sulfide Occurrences by Spreading Centers

	Area	Year of Discovery	National Involvement	Minerals Zn %	Cu %	Pb %	Ag ppm	Au ppm	Volume of Deposit (m^3)
A	Juan de Fuca	1981	U.S.	55	0.35	0.32	3 00		100,000
B	Gorda Ridge	1981	U.S.			Not Avail.			NA
C	Guaymas Basin	1980	U.S./Mex.	30	1.0	0.1	3 00		1,200,000
D	E. Pac Rise 21°N	1978	US/Mex/Fr.	50	0.75	0.35	4 00	Tr	18,200
E	E. Pac Rise 13°N	1981	France			Not Avail.			NA
F	Galapagos Rift	1981	U.S.	0.1	10.0	0.1	3 00		8,000,000
G	E. Pac. Rise 20°S	1981	US/Fr.			Not Avail.			NA
	Mid-Atlantic 37°N	1974	US/Fr.	Fe/Mn Oxides				NA	
	Red Sea Atl, II	1948/63	Sw/US/UK	5	1	Tr	Tr		20,000,000

* Based on estimates of dimensions of deposits observed by bottom photography and manned submersible (Density approx. 2.5 gm/cc).

Source: Table IV-2 and IV-3: Cruickshank, Michael J. The Case for Accelerated Ocean Mining. Ocean Industry, Mar. 1982, p. 28.

Estimates of the extent and volume of the deposits are based on geologic hypothesis and limited observational information. Exclusive of the Red Sea, which will be discussed in a following section, only four of the spreading sites sampled have been found to contain what appear to be massive deposits of polymetallic sulfides: Juan de Fuca, Guaymas Basin, East Pacific Rise at 21 degrees N, and Galapagos Rift. These four sites have yielded a total of about 1,000 pounds of material. Present and future research will undoubtedly alter any tonnage or value estimates made at this time.

A further note of caution may also be in order. Many parallels exist and will be drawn in subsequent sections to the cost of recovery and impacts of ferromanganese nodule mining. A parallel in economic speculation also exists. Early speculative estimates of the tonnages of ferromanganese nodules in the Pacific Ocean were given by John Mero in 1965 as 1.66 trillion metric tons. 31/ This was subsequently rounded to 1.5 trillion tons and expressed

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31/ Mero, John L. The Mineral Resources of the Sea. Elsevier Publishing Company, New York, 1965, 312 p.

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with caviates as to what might be potentially mineable (10 billion to 500 billion tons). 32/ However, the number 1.5 trillion tons became the figure

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32/ Mero, John L. Potential Economic Value of Ocean-Floor Manganese Nodule Deposits. In Ferromanganese Deposits on the Ocean Floor, Horn, David R., Editor, National Science Foundation, IDOE, Washington, D.C., 1972, p. 202.

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that was widely quoted and popularized, engendering a common belief at the time that the deep seabed nodules represented a virtually limitless untapped

resource; a wealth that, in addition to petroleum from offshore beyond the limits of national jurisdiction, could be developed to the preferential benefit of less developed nations. This was a basic premise upon which the Third U.N. Conference on the Law of the Sea was founded. Economic change and subsequent research have indicated both a more limited mineable resource base and much lower projected rates of return from nodule mining. However, as often happens, positions that become established on the basis of one set of assumptions are difficult to amend when the underlying assumptions change.

In parallel fashion, creating expectations on the basis of highly speculative estimates of recoverable tonnages and values for hydrothermal metal deposits would seem to serve little purpose. Avoiding the present temptation to extrapolate into enormous dollar values could avoid what may upon further research prove to be less than a spectacular economic resource in terms of recovery. This is not to say that the resource may not be found, but simply that it is premature to define its economic value.

In order to cast the potential economic significance for the United States of hydrothermal sulfide deposits into some perspective, it would be particularly useful to consider the uses and present resource availability of the major metals found in polymetallic sulfide deposits. These data for copper, silver, and zinc are discussed in the following sections with particular reference to U.S. production and imports.

Copper

Civilian and Defense Uses

Copper has been one of the more important materials in the advance of industry, technology, and the arts. More than half of the domestic use of copper goes into electrical applications such as motors, generators, power distribution facilities, industrial controls, communications equipment, and house wiring. Copper is also consumed in many nonelectrical applications such as roofing, plumbing, decorative items, heat exchangers, shell casings, instruments, household utensils, jewelry, and coinage.

Production, Consumption, and Prices

Domestic mine production in 1981 was 1.7 million tons of copper, valued at $2.8 billion. World mine production and reserve base figures for 1981 are given in table IV-4. Apparent domestic consumption (primary plus old scrap) was 2,620,000 tons. The domestic producer price averaged $0.85 per pound in 1981 and the average price on the London Metal Exchange was $0.81 per pound.

TABLE IV-4. Copper Mine Production and Reserve Base
(data in thousand s.t. of metal)

Country	1981 Mine Production	Reserve Base
United States	1,680	99,000
Australia	200	18,000
Canada	760	35,000
Chile	1,150	107,000
Papua New Guinea	170	15,000
Peru	400	35,000
Philippines	320	20,000
South Africa, Republic of	230	6,000
Zaire	500	33,000
Zambia	630	37,000
Other Market Economy Countries	840	85,000
Poland	330	14,000
U.S.S.R.	1,030	40,000
Other Central Economy Countries	390	12,000
World Total	86,000	556,000

Foreign Sources and Import Dependence

In 1981 the net import reliance as a percent of apparent copper consumption was five percent. Major import sources averaged over the 1977-80 period were:

Chile, 29 percent; Canada, 23 percent; Peru, 14 percent; Zambia, 12 percent; and Others, 22 percent.

Conservation, Recycling, and Substitution Research and Development

Old scrap, converted to refined metal and alloys, provided 670,000 tons of copper, or 26 percent of apparent consumption. New scrap, from fabricating operations, yielded 870,000 tons of copper. Copper is amenable to substitution for many uses such as aluminum for electrical applications, steel for shell casings, and plastics for plumbing. 33/

33/ References: Schroeder, H.J. U.S. Department of Interior, Bureau of Mines. Mineral Commodity Profiles, 1979, 20 p.; and Mineral Commodity Summaries 1982, p. 40-41.

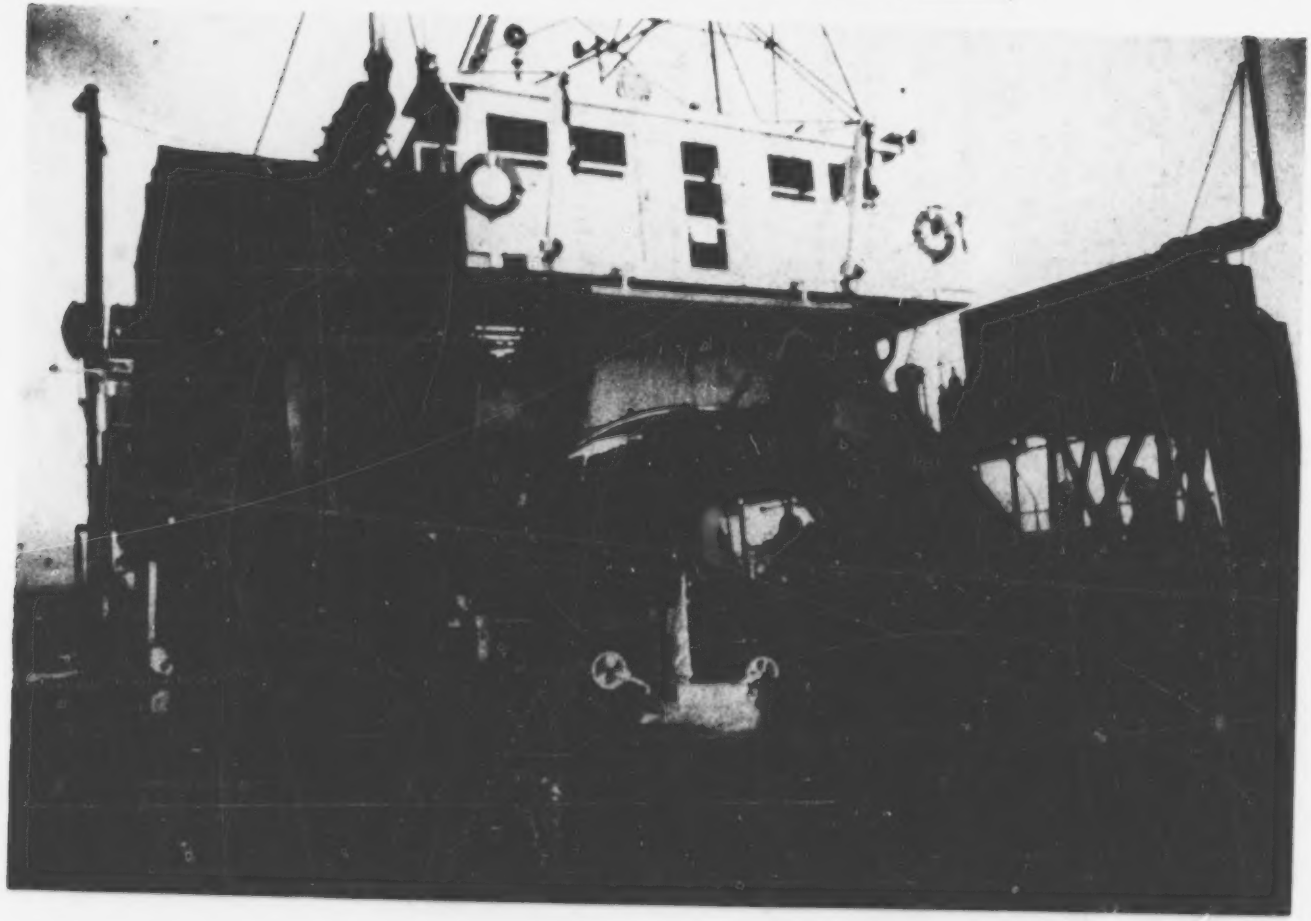
Silver

Civilian and Defense Uses

The major use of silver in the United States is in photography which amounted to 35 percent of U.S. consumption in 1981. Photography is based almost entirely on light-sensitive silver halides. Silver salts are essential for color photography and unsurpassed for clarity of image definition in black and white photography. Other major uses include electrical and electronic components, silverware and jewelry, brazing alloys and solders. Silver is extremely important in any war effort, particularly for its essential uses in photography and electrical applications.

Plate 9. DSRV Alvin operated by Woods Hole Oceanographic Institution
(Photo courtesy of the National Science Foundation)

Plate 10. DSRV Alvin and tender ship Lulu
(Photo courtesy of the National Science Foundation)



Production, Consumption, and Prices

Domestic mine production in 1981 was 37.5 million troy ounces of silver content valued at $412 million. Production came from 225 mines mostly in Idaho and Arizona. About 55 percent of the mine production was a byproduct of copper, lead, and zinc mining. World mine production and reserve base data for 1981 are given in table IV-5. Apparent domestic consumption was 175 million troy ounces. The domestic producer price in 1981 averaged $11.00 per troy ounce.

TABLE IV-5. Silver Mine Production and Reserve Base
(data in million troy ounces of metal)

Country	1981 Mine Production	Reserve Base
United States	37.5	1,820
Canada	38.0	1,600
Mexico	50.0	1,060
Peru	48.0	610
Other Market Economy Countries	100.0	1,345
Central Economy Countries	84.0	2,000
World Total	357.5	8,435

Foreign Sources and Import Dependence

In 1981 the net import reliance of the United States for silver was 50 percent of apparent consumption. Major import sources averaged over the 1977-80 period were: Canada, 40 percent; Mexico, 24 percent; Peru, 22 percent; United Kingdom, 5 percent; and Others, 9 percent.

Conservation, Recycling, and Substitution Research and Development

Old scrap silver recycled in the United States in 1981 was estimated at 50 million ounces accounting for 37 percent of total consumption. Rhodium and aluminum can be substituted for silver in mirrors and reflecting surfaces. Stainless steel is an alternate material in common use for table flatware. Xerography and other copying methods have somewhat reduced demand for silver halides. In surgical uses such as plates, pins, and sutures tantalum can be used as a substitute. 34/

34/ References: Drake, H.J. U.S. Department of Interior, Bureau of Mines. Mineral Commodity Profiles, 1978, 14 p.; and Mineral Commodity Summaries 1982, p. 138-139.

Zinc

Civilian and Defense Uses

Metallic zinc is used in four major areas: galvanizing, brass and bronze products, castings, and rolled zinc. Significant quantities of zinc are also consumed as pigments and other chemicals. The construction industry is the major market for zinc coated materials.

Product, Consumption, and Prices

Domestic zinc mine production in 1981 is estimated at 340,000 tons valued at $306 million. World mine production and reserve base data are given in table IV-6. Apparent domestic consumption was 1,260,000 tons. The average price of zinc metal on the U.S. market was 44.8 cents per pound in 1981.

TABLE IV-6. World Zinc Production and Reserve Base
(thousand short tons metal)

Country	1981 Mine Production	Reserve Base
United States	340	53,000
Australia	560	26,000
Canada	1,100	68,000
Mexico	280	3,000
Peru	560	8,000
Other Market Economy Countries	2,040	79,000
Central Economy Countries	1,570	26,000
World Total	6,450	265,000

Foreign Sources and Import Dependence

The United States in 1981 was 67 percent import dependent for zinc. The major foreign sources as a percentage of total imports for the period 1977-80 were:

Ore and concentrates: Canada, 50 percent; Peru, 16 percent; Honduras, 10 percent; and Others, 24 percent.

Metal: Canada, 49 percent, Spain, 8 percent, Mexico, 7 percent; Australia, 6 percent; and Others, 30 percent.

Conservation, Recycling, and Substitution Research and Development

In 1981 recycling produced about 44,000 tons of slab zinc or about five percent of slab zinc consumption. In addition about 30,000 tons of zinc dust and 33,000 tons of zinc oxide were produced from scrap. Aluminum, plastic coatings, and paints can replace zinc to some extent for corrosion protection. Aluminum and magnesium are suitable substitutes for zinc in diecasting, and aluminum, magnesium, titanium, and zirconium are substitutes in chemicals and pigments. 35/

35/ References: Cammarota, V.A., Jr. Zinc. U.S. Department of Interior, Bureau of Mines. Mineral Commodity Profiles, 1978, 25 p.; and Mineral Commodity Summaries 1982, p. 174-175.

COST ESTIMATES FOR DEEP SEA MINING

If the extent of potential metals recovery from polymetallic sulfide deposits is unknown, or speculative at best, the cost of mining them utilizing an undefined technology is even more speculative at this time. However, some suggestion of the possible magnitude of the costs involved might be gained from analogy to the projected cost of deep seabed manganese nodule mining. While the mining system would not be identical, other aspects such as ship operating and construction costs, processing and transportation may be comparable.

Deep Seabed Ferromanganese Nodule Mining

Two main types of mining systems have been developed for deep ocean nodule recovery; hydraulic and continuous line bucket (figure IV-1). Hydraulic systems use either pumped water or air to raise the nodules through a pipe from the seafloor. The collector head can either be towed or self propelled. Consortia involving U.S. participants favor hydraulic systems. Nodules would be transferred from the mineship to ore carriers for transport to shore.

Onshore facilities would process the nodules for either three of four primary metals. A "three-metal" plant would extract nickel, copper, and cobalt as primary products and could produce secondary products such as molybdenum. A "four-metal" plant would recover manganese as a primary product in addition, but since manganese is in much greater abundance in nodules relative to the other metals, only a limited number of operations would be expected to produce manganese before the market would become saturated and the further extraction of manganese would not be economic.

Estimates of capital costs and operating expenses for deep seabed manganese nodule mining are continuously being updated. While no consortia for deep ocean mining has actually progressed to commercial scale recovery, cost estimates based on projections from pilot scale operations are fairly firm. These estimates can be broken into two categories based on the number of metals for which recovery and marketing is envisioned. One basic category of nodule mining operation would produce copper, nickel, and cobalt from nodules mined at the rate of three million tons per day (dry weight) per mine site. The alternative (for ventures desiring to produce manganese in addition to the other three metals) would be viable at a lower nodule mining rate of one to two million tons per year. Projected cost estimates for three- and four-metal nodule mining operations are given in table IV-7. These data indicate that in both three- and four-metal categories, the capital investment for the total mining operation would be on the order of one billion to 1.5 billion dollars per minesite. However, greater returns could be realized from multiple site development through amortization of research and development costs over a broader base. For the sake of comparison, a second set of assumptions regarding the cost of financing a nodule mining venture are given in appendix II.

TABLE IV-7. Capital and Operations Cost of Deep Seabed Projects

	Annual tonnage 3 million tons (dry) Three metals	2 million tons (dry) Four metals
Capital costs, $U.S. 1,000,000		
Research and development	200	150
Mining and Transport	450	350
Processing	400	550
Working capital	200	275
Total	1250	1325
Annual operational costs, $U.S. 1,000,000		
Mining	100	80
Transport	70	50
Processing	100	270
Total	270	400

Source: Cruickshank, Michael J. The Status of Deep Sea Mining, Ocean Industry, Oct. 1981, p. 94.

The economic future of deep seabed mining is uncertain. At present the primary impediments to commercial deep seabed mining are the uncertain international legal and political structure, uncertainty of future metals markets, and uncertainty about the growth of the world economy. These impediments coupled with the projected future economic performance of the ventures, and possible environmental risks, influence the investment climate. Predicted economic performance of seabed mining ventures can be adversely affected by delays between initial investment and receipt of revenues. Further, the long start-up and operating period require predicting both metal prices and the structure of the metals market over an extended period of time. The

probability that major changes such as technological advances, could occur during this interval, increases as the time frame is extended. At this point no one really knows whether the initial deep seabed mining ventures will be economically viable. 36/

36/ U.S. Department of Commerce, National Oceanic and Atmosphere Administration. Deep Seabed Mining, Report to Congress, Dec. 1981, p. 35.

Polymetallic Sulfide Mining

Utilizing the estimates for deep seabed nodule mining given above, some estimate of the scale of costs likely to be encountered from polymetallic sulfide recovery can be derived. In both cases a mine ship is likely to be needed either as a platform for the deployment of a pipestring and dredge head arrangement or for controlling independent drones or manned submersibles. In addition transport vessels would be needed to ferry the mined ore to a shore based processing facility. Thus, by comparison, the mine ship and transport vessels would likely cost on the order of $400 million to $500 million. Capital costs for new processing facilities, if needed (see below), could run on the order of $300 million to $500 million and research and development costs could fall in the range of $100 million to $200 million. Based on these assumptions the overall polymetallic mining venture capital cost would likely fall in the range of one to 1.5 billion dollars or roughly comparable to the cost of a deep ocean nodule mining operation.

Annual operating costs of mining, transport, and processing could also be comparable to nodule mining with possible differences tending to counterbalance one another or possibly favoring the hydrothermal deposits. These differences would likely involve higher extraction costs for polymetallic sulfide deposits from having to first break the deposits into pieces which can be raised to the surface. On the other hand, the shallower depth of the hydrothermal vent deposits (8,000 feet versus 18,000 feet for nodules) would tend to reduce mining costs. The more concentrated nature of hydrothermal deposits versus the more dispersed nature of nodules which form slowly by concretion on the surface of the seabed may be an advantage for polymetallic sulfide recovery. If the mine site were in the Juan de Fuca or Gorda rift, transportation costs to the U.S. mainland would be lower. Also the chemical processing and metal extraction from the sulfide minerals would be less complex and consequently operational processing costs would tend to be lower than for nodule processing. Polymetallic sulfides could also be processed in existing smelters.

NOAA has taken steps to acquaint industry with the commercial potential of polymetallic sulfide deposits. After recovering polymetallic sulfide samples from the Galapagos Rift, NOAA called a meeting in December 1981 to explain the signficance of the discovery to the major extractive and related industries. 37/ One purpose of the meeting was to discuss

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37/ Representatives of the following industries or industrial organizations were among those present: Ocean Mining Associates, American Mining Congress, AMAX Exploration, Kennecott Corp., INCO Ltd., Standard Oil of Indiana, Lockheed Missiles and Space Co., Reynolds International, Inc., Global Marine Development Corp., U.S. Steel Corp., Sunoco Energy Development Co., St. Joe Minerals Corp., and American Copper and Nickel Co., Inc.

the economic feasibility of mining hydrothermal vent deposits. It was generally agreed that since industry has already developed mining equipment for the recovery of manganese nodules, it would be well within the capabilities of present day technology to develop cost-effective dredging equipment to fragment the sulfide ore and raise it to the surface. 38/ It is a further goal

38/ Barrows, Joan B. Polymetallic Sulphides: Frontiers in Ocean Mineral Exploitation. Paper (unpub.) presented to Marine and Coastal Geology Section, Annual Meeting of the Association of American Geographers, San Antonio, Texas, Apr. 26, 1982.

of NOAA over the next few years to provide American industry with enough research and assessment data on the Gorda and Juan de Fuca Ridges for industry to determine if the deposits warrant commercial development. 39/

39/ Ibid.

OCEAN MINING INTERESTS

Since their recent discovery, commercial interest in polymetallic sulfides has not progressed much beyond a stage that could be described as maintaining active awareness. Research and exploration that could be characterized as primarily commercially directed in nature is, as yet, a future possibility. That it will occur would appear likely, but when is a matter of corporate decision not yet made.

Who the early entry might be is only a matter of speculation. Research efforts into the nature and formation of the sulfide deposits are of an international scope. These activities which are not related to private commercial activities have been discussed in chapter III.

Speculation as to potential mining interests would suggest that the consortia which have been formed for mining deep ocean nodules would have some early advantage through their existing organizational structures, related interest and expertise. Of these consortia four contain U.S. firms: the Kennecott Consortia, Ocean Mining Associates, Ocean Management Incorporated, and Ocean Minerals Company. Tables IV-8 through IV-11 give details as to the composition of each consortia, nationalities and activities of the firms involved. In addition two other national consortia one French and one Japanese, have directed activities toward commercial recovery of deep seabed nodules. These are described in tables IV-12 and IV-13.

While these firms are the most likely current prospects for early entry into future polymetallic sulfide mining that is not to say that any are now actively pursuing research and technology development uniquely of this nature. The focus of their investment arrangements is toward recovery of deep seabed nodules, the potential commercial recovery of which is still facing major go/no go decisions. Until these decisions are made, and considering the generally cautious investment climate facing industry today, it would not seem reasonable to expect that existing ocean mining ventures are immediately likely to become commercially active in polymetallic sulfide recovery. Some expenditure of research and exploration funds may occur, but this is likely

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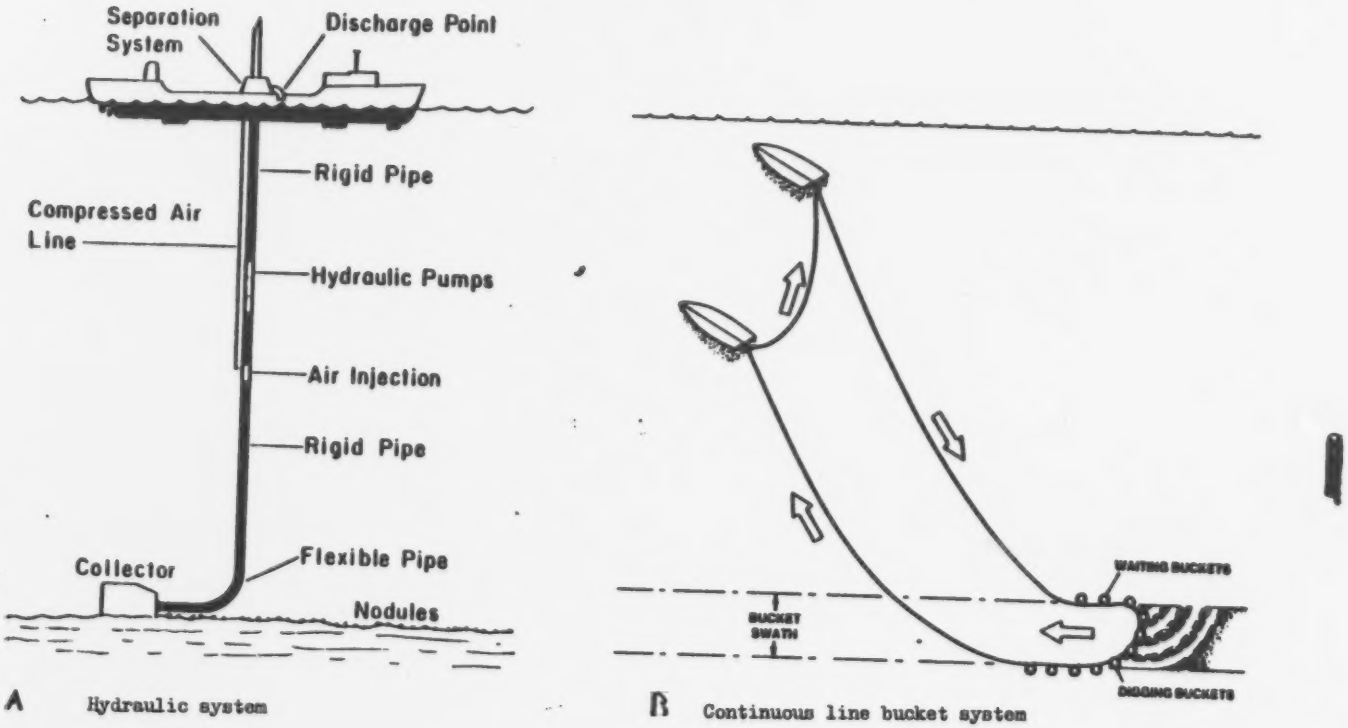
FIGURE IV-1. Diagrams of two major nodule mining systems.



Source: NOAA, Deep Seabed Mining, Report to Congress, Dec. 1981, p. 22.

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to be on a limited basis and possibly in conjunction with or support of government and academic research efforts. While this would appear to be the current investment expectations, commercial interest could heighten dramatically pending favorable reports of further research in vent areas, particularly with regard to possible ease of materials recovery and high metals analyses.

As with deep seabed nodule mining, a second type of commercial interest exists. This industry is the consulting industry which plays an active and important role in the evolution and study of new technology development. Since service industries are part of the equation of basic ocean mining interests and potential economic significance, this aspect is mentioned here.

HYDROTHERMAL ORE DEPOSITS--NEAR TERM ECONOMIC BENEFIT

Whether or not submarine hydrothermal deposits prove to be mineable, the economic benefits of research will be felt in the increased understanding of the processes forming the deposits, and through this knowledge better means of exploration and mining may be gained. Hydrothermal deposits are formed by chemical precipitation from hot water solutions. They represent one of the most economically important classes of ore deposits, supplying much of the world's copper, zinc, lead, silver, gold, tin, molybdenum, and other metals. There are five major factors of formation:

1. A source of the ore metals;

2. A source of water that dissolves and later precipitates the metals, concentrating them in the process;

3. A source of heat;

4. A pathway for the solution; and

5. A site for deposition of the metals.

Variations in these factors account for the great variety of hydrothermal ore deposits. 40/

40/ Mottl, Michael J. Submarine Hydrothermal Ore Deposits. Oceanus, v. 23, no. 2, Summer 1980, p. 19-27.

As discussed in chapter II, in the formation of marine polymetallic sulfide deposits, the unique environment at ocean spreading centers provides the needed combination of factors for hydrothermal mineral deposition:

1. The source of metals is oceanic crust;

2. Seawater is the source of water (more saline, hotter water has greater capability to dissolve metals);

3. Magma is the heat source (new ocean crust);

4. The new crust fractures as it cools and tensional forces pull it apart;

5. The minerals are deposited on the seafloor or just below it as the hot metal brines mix with cold ocean water.

A number of factors can increase the ability of a potential ore fluid to transport and deposit metals. Heat and salinity are known to be important in submarine hydrothermal deposits, and work is currently underway to determine what impact acidity may have in these natural settings. The Red Sea metalliferous muds are an example of deposition from a very saline hydrothermal solution.

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TABLE IV-8. Ocean Mining Associates

Year of Formation	Country of Registration	Head Office	Service Contractor
May 1974	partnership registered in Virginia U.S.A.	Gloucester Point, V Virginia	Deepsea Ventures, Inc. (Gloucester Point, Va.)

COMPOSITION OF CONSORTIUM

Participants	Parent Company	Country of Origin of Parent Company	Share of Participation (%)	Major Activities of Parent Company
Essex Minerals Co.	U.S. Steel Corp.	U.S.A.	25	Steel manufacturing and fabrication
Union Seas Inc.	Union Minière S.A.	Belgium	25	International mining company, active in Belgium, Canada, U.S.A., Australia.
Sun Ocean Ventures	Sun Company, Inc.	U.S.A.	25	Non-operating company in oil and gas
Samin Ocean, Inc.	Ente Nazionale Idrocarburi (ENI)	Italy	25	Italian State Oil Company, engaged in exploration, production and marketing of oil.

Source, tables IV-8 through IV-12: United Nations, Ocean Economics and Technology Branch, Department of International Economic and Social Affairs. Summary Tables of Major Deepsea Mining Investors, Mar. 1982.

TABLE IV-9. Kennecott Consortium

Year of Formation	Country of Registration	Head Office	Service Contractor
January 1974	unincorporated	-	-

COMPOSITION OF CONSORTIUM

Participants	Parent Company	Country of Origin of Parent Company	Share of Participation (%)	Major Activities of Parent Company
Kennecott Consortium	Sohio *	U.S.A.	40	Production and marketing of oil, coal and other minerals.
RTZ Deepsea Enterprises Ltd.	Rio Tinto-Zinc Corp. Ltd.	U.K.	12	International mining company in aluminum, copper, gold, lead and zinc.
Consolidated Gold Fields PLC	same	U.K.	12	International mining finance company with major interests in gold.
BP Petroleum Development Ltd.	British Petroleum Co. Ltd.	U.K.	12	Major oil company with other mineral interests.
Noranda Exploration Inc.	Noranda Mines, Ltd.	Canada	12	Mining and metallurgy of copper, lead and zinc.
Mitsubishi Group	Mitsubishi Corp. Mitsubishi Metal Corp. Mitsubishi Heavy Industries, Ltd.	Japan	12	General trading company, mining, heavy industry.

* BP owns majority stock in Sohio.

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TABLE IV-10. Ocean Management Incorporated

Year of Formation	Country of Registration	Head Office	Service Contractor
February 1975	incorporated in U.S.A.	administrative office in New York, NY	-

COMPOSITION OF CONSORTIUM

Participants	Parent Company	Country of Origin of Parent Company	Share of Participation (%)	Major Activities of Parent Company
Inco, Ltd.	same	Canada	25	The largest producer of nickel in the world. Also engaged in batteries and formed metal products.
AMR (Arbeitsgemeinschaft Meerestechnischgewinnbare Rohstoffe)	Metallgesellschaft AG	Federal Republic of Germany	25	Mining, refining, fabricating, and trading of metals
	Preussag AG			Non-ferrous metals, coal and petroleum Red Sea mods development
	Salzgitter AG			Holding company in steel making and shipbuilding
SEDCO, Inc.	same	U.S.A.	25	Contract drilling and support operations for mainly offshore oil
Deep Ocean Mining Co. Ltd. (DOMCO)	23 companies	Japan	25	Including trading, mining, and manufacturing companies and banks

TABLE IV-11

Ocean Minerals Company (OMCO)

Year of Formation	Country of Registration	Head Office	Service Contractor
November 1977	U.S.A. partnership	Mountain View, California	

COMPOSITION OF CONSORTIUM

Participants	Parent Company	Country of Origin of Parent Company	Share of Participation* (%)	Main Activities of Parent Company
Amoco Ocean Minerals Company	Standard Oil of Indiana	USA	30.7%	Oil company.
Lockheed Systems Company, Inc.	Lockheed Aircraft Corp.	USA	30.7%	Production of aircraft, missiles and spacecraft.
Ocean Minerals, Inc.	Lockheed Missiles and Space Co., Inc. (subsidiary of Lockheed Aircraft Corp.)	USA		
	Billiton BV (a Netherlands company of the Royal Dutch/ Shell group)	Netherlands	30.7%	Billiton is engaged worldwide in all stages of the mineral industry. The Royal Dutch/Shell group is a group of companies in the oil, chemicals, coal and minerals industries and related industries.
		USA		
	BKW Ocean Minerals BV (a Netherlands subsidiary of the Royal Boskalis Westminster Group, NV)	Netherlands	7.9%	The Royal Boskalis Westminster Group is mainly engaged in dredging, land reclamation and civil engineering.

*Shares of participation are as of February, 1982. It is possible that these shares may vary over time.

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TABLE IV-12. Association Francaise poul l'Etude et la Recherche des Nodules (AFERNOD)

Year of Formation	Country of Registration	Head Office	Service Contractor
1974	France	Paris	-

COMPOSITION OF ASSOCIATION

Participants	Major Activities
Centre National pour l'Exploitation des Oceans (CNEXO)	French Public Corporation, research and development in oceanology; living and mineral resources; environment; offshore and under-water technology; energy.
Commissariat à l'Energie Atomique (CEA)	National Center for Atomic Energy Remote control equipment and minerals processing
Société Métallurgique le Nickel (SLN)	Production and processing of nickel.
Chantiers de France-Dunkerque	Shipbuilding ; heavy industry; engineering and offshore constructions.

TABLE IV-13. Deep Ocean Minerals Association (DOMA)

Year of Formation	Country of Registration	Head Office	Service Contractor
March 1974	Japan as a public corporation	Tokyo	-

COMPOSITION OF ASSOCIATION

MEMBERS		MEMBERS	
C. Itoh and Company, Ltd. Kanematsu-Gosho Ltd. Marubeni Corporation Mitsubishi Corporation Mitsui and Company, Ltd. Nichimen Company, Ltd. Nissho Iwai Corporation Sumitomo Corporation	trading companies	Hitachi Shipbuilding and Engineering Company, Ltd. Ishikawajima-Harima Heavy Industries Company, Ltd. Kawasaki Heavy Industries Co. Ltd. Mitsubishi Heavy Industries, Ltd Mitsui Engineering and Shipbuilding Company, Ltd. Nippon Kokan K.K. Sumitomo Heavy Industries, Ltd. Ebara Engineering Company, Ltd. Meidensha Electric Company, Ltd.	shipbuilding and heavy industries
Dowa Mining Company, Ltd. Furukawa Company, Ltd. Japan Metals and Chemicals Company, Ltd. Mitsubishi Metal Corporation Mitsui Mining and Smelting Company, Ltd. Nippon Mining Company, Ltd. Nippon Yakin Kogyo Company, Ltd. Nittetsu Mining Company, Ltd. Pacific Metals Company, Ltd. Sumitomo Metal Mining Company, Ltd.	mining and metallurgy companies	Kawasaki Steel Corporation Kobe Steel, Ltd. Nippon Steel Corporation Sumitomo Metal Industries, Ltd.	steel companies
		Yuso Kaiun Kaisha, Ltd. Mitsui O.S.K. Lines, Ltd. Nippon Yusen K. K.	shipping companies
		The Fujikura Cable Works, Ltd. Sumitomo Electric Industries, Ltd.	cable companies
		Nippon Electric Co., Ltd. Victor Co. of Japan, Ltd.	electric appliances
		Kyokuyo Co., Ltd.	fisheries

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Red Sea Deposits

Although the Red Sea metalliferous muds have not attracted much attention internationally, they may be the target of the first deep sea mining operation. Of interest not only for their potential economic value, the area is one of intense submarine hydrothermal activity and may serve as a model for exploration of other such deposits (figure IV-2). In addition to the scientific significance the issue of mining seems to have been settled with a joint agreement in 1974 between Saudi Arabia and Sudan, the bordering countries (see chapter V). 41/

41/ Georghiou, L. and G. Ford. Arab Silver from the Red Sea Mud, New Scientist, Feb. 1981, p. 470-472.

The Red Sea is an embryonic ocean basin which has formed by rifting (pulling apart of land masses). In an oversimplified view, the Red Sea can be thought of as a precurser or early stage of a major ocean. In this analogy, one can easily picture the similarities between the hydrothermal activities of the spreading Red Sea basin and those of deep sea spreading centers such as 21 degrees North or the Galapagos (figure IV-3).

The Resource

The resource consists of thick layers of metal-bearing muds that have collected in deep pools of the sea floor, at approximately 2,000 meters depth. The muds are rich in silver, zinc, and copper and several other metals. The metals are concentrated in layers of sulfides alternating with oxides and silicates. The muds, 10 to 30 meters thick, line the bottom of pools of dense hot (60 degrees C) brines. The subsurface circulation and related chemical reactions

FIGURE IV-2. Location of Red Sea Deeps with Hydrothermally Influenced Sediments

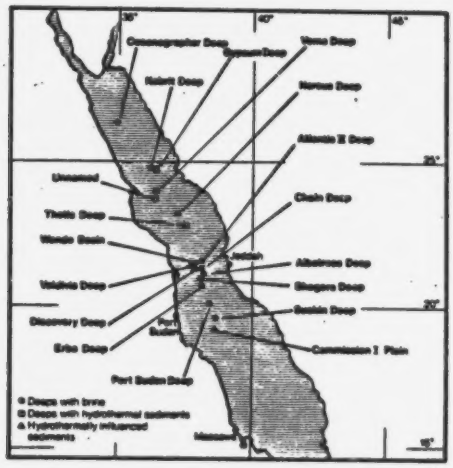
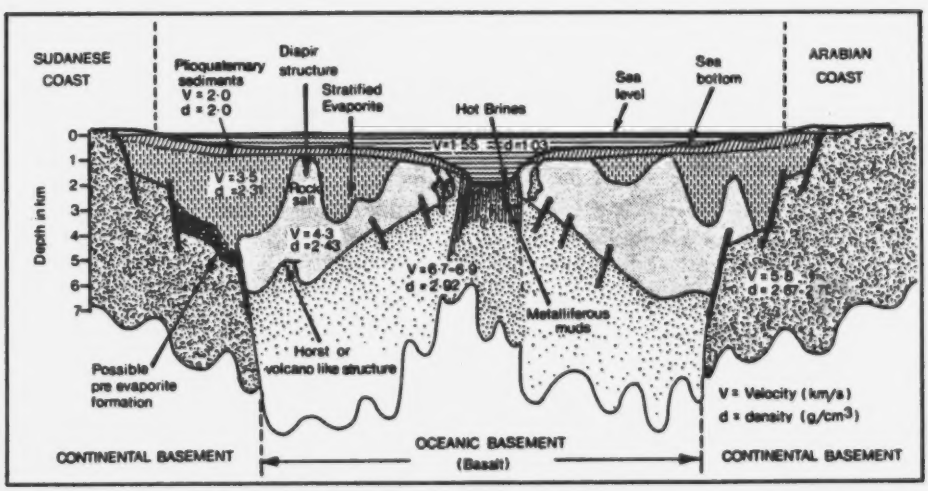


FIGURE IV-3. Tectonic Model Cross Section in the Central Red Sea



Source: Mining Magazine, Aug. 1981.

that take place are not well understood, but as in hydrothermal vent activity discussed earlier, it appears that sea water migrates downward through fractures along the spreading ridge, picks up metals and heat and returns to the sea floor.

The brine pools were first discovered in the 1960's; 18 have been identified, but one, the Atlantis II Deep, has the most attractive economic potential. Metalliferous sediments have been precipitating in this pool for the last 25,000 years, forming a complexly layered deposit with a thickness of 15 to 100 feet over 25 square miles. Average grades of the material that would be mined are approximately three to six percent zinc, one percent copper, and 50 grams per ton silver. 42/

42/ Shanks, W.C. Economic and Exploration Significance of Red Sea Metalliferous Brine Deposits, paper presented at SME-AIME Annual Meeting, Dallas, Feb. 1982, 7 p.

Potential For Mining

The German company, Preussag, has undertaken a feasibility study under a $20 million contract from the Red Sea Commission. Preussag mined and concentrated approximately 20,000 cubic yards of mud from four mine sites in the Atlantis II Deep over a three-month period in 1979. 43/ The pre-pilot mining

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43/ Ibid.

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test demonstrated mining capabilities at 6,500 feet depth using a conventional five-inch drill string and suction head with a conical vibrating

screen, all hung below the mining ship (figure IV-4). The mud, too thick to be pumped as is, is broken up by the vibrating screen and jets of sea water which are pumped into the mud. The pump and electric motor are hung from the pipes to raise the mud to the ship.

Rather than transport the mud and metals mixture 95 miles to shore, the metals were concentrated at sea on board the ship. Concentrates were produced continuously with 30 to 35 percent zinc, 3.5 to 4.5 percent copper, 500 to 700 grams per ton silver and a few parts per million gold at 60 to 70 percent recovery rates. The process, called froth flotation, is well established, but needs some adaption for use at sea. Preussag demonstrated the concentration process at sea in pilot testing with disposal of the tailings 1,300 feet below the surface with minimal environmental impact.

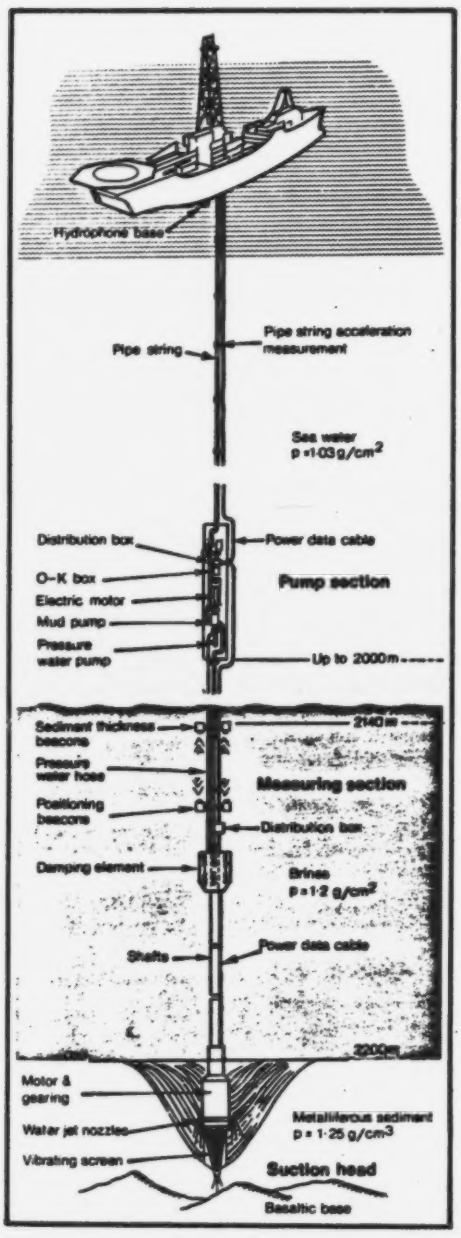
Pre-pilot testing indicates that the necessary technology is available at a cost that may be economically feasible. Future prospects for mining depend on additional metallurgical testing (for further concentration of the metals) and a year long pilot mining test at one-tenth scale. 44/

44/ Georghiou and Ford, Arab Silver from the Red Sea Mud, 1981.

Economic Potential

At first glance the economic potential seems massive. The Atlantis Deep alone is estimated to contain 1.7 million tons of zinc, 0.4 million tons copper, and 5,000 tons of silver worth several billion dollars at

FIGURE IV-4.



Main components of the mining system designed and developed for the SSRSC's pre-pilot mining test on metalliferous muds in the Red Sea deep, Atlantis II. The test was carried out in 1979, using the oil exploration drilling ship, *SEDCO 445*.

Source: Mining Magazine, Aug. 1981.

current prices. 45/ The Red Sea Commission plans to extract metals worth

45/ Shanks, Economic and Exploration Significance of Red Sea Metalliferous Brine Deposits, 1982.

up to $170 million annually. Almost half of the revenues are calculated to come from silver. 46/ Sales, of course, will be dependent on a historically volatile

46/ Georghiou and Ford, Arab Silver from the Red Sea Mud, 1981.

metal market.

Under the most optimistic scenario, the Atlantis II Deep minesite might be established four to six years after completion of a year long pilot mining test to be conducted in 1983-84. Mining would produce 100,000 tons per day of wet mud with 200 tons per day of contained zinc and proportional amounts of copper and silver. The expected mine life would be 15 to 20 years. 47/

47/ Anonymous. Two Thousand Meters Under the Sea, Mining Magazine, Aug. 1981, p. 114-122.

Similarity to Land-Based Deposits and Implications for Exploration

Another important factor when considering the potential economic benefits in the research of hydrothermal vent systems is the usefullness of that knowledge in the exploration of related land-based deposits. Scientists have noted many similarities between the hydrothermal vent systems and several land-based mineral deposits which are currently economically viable. Through

better understanding of the vent mineralization process currently in action, exploration for new land-based deposits and development of known deposits can be conducted with new insight.

Research related to ocean spreading centers has been an important contribution to the study of plate tectonics. In the past two decades the theory of plate tectonics had tied together many geologic features that were once thought to be the result of distinct and separate processes. The hypothesis has given a more integrated picture of continental evolution. Through plate tectonics one can envision the dynamics of the earths crust, thus the movement of materials created or deposited on the ocean floor onto (or into) land masses. Such is the case, it is suggested, with the Cyprus mineral deposit. 48/

48/ Edelson, Edward. Prospecting with Plate Tectonics. Mosaic, Nov./Dec., 1981, p. 9-13.

Cyprus is a classic example of "displaced" ocean floor in a present day land mass, where the Troodos massif has been mined for copper and other minerals for several hundred years. Several key characteristics of "Cyprus" type deposits, found in many locations throughout the world, relate to the hydrothermal vents active on the ocean floor today:

1. Association with ophiolites - rocks that originated as part of a marine sequence and have since been deformed, and are now often found on land;
2. Deposits are often located in or near pillow laval indicating their association with fossil submarine volcanism;
3. Similar mineralogy;
4. Mineralization associated with relict faults; and
5. Evidence of seawater interaction.

During the past 50 years, six million tons of ore have been mined from several ore bodies on Cyprus, the largest of these producing 2.1 million tons (Kalavasos Mine). Estimates of remaining ore are four million to one million tons per ore body. Analyses of the ores show that sulfur (0.0 to 50.0 percent), copper (0.1 to 12.0 percent), zinc (0.1 to 1.0 percent), nickel (30 to 138 part per million), and cobalt (40 to 600 parts per million) are the dominant potentially economic metals. 49/ The Cyprus area has been

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49/ Malahoff, Alexander. Polymetallic Sulfides Form the Oceans to the Continents. Sea Technology, Jan. 1982.

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an important source of metals. Through further exploration of the hydrothermal vent deposits and comparison with Cyprus, new discoveries may be possible which may not have been envisioned otherwise.

Other Environments

Most of the hydrothermal activity in the oceans occurs along the mid-ocean ridge systems, however, other non-ridge areas may prove to be environments of extensive metal mineralization. Such areas may include: (1) marginal seas behind island arcs such as the Sea of Japan; and (2) bases of volcanic island arcs such as Loihi seamount, an extension of the Hawaiian chain. The hydrothermal processes in these areas are expected to be similar in many ways, but two factors which could make them different are: the higher water and silica content of the magmas. The higher water content is expected to be more

acidic and metal rich, and the higher silica content would be associated with different metal concentrations (higher lead content in particular) than are the basalts of the mid-ocean ridges.

The massive sulfide deposits of the Kosaka District of Japan, known as the Kuroko (black ore) Deposits, are an example of a submarine island arc ore deposit containing rich accumulations of copper, lead, zinc, and silver. Isotope studies and studies of fluid inclusions in the minerals have shown these deposits to be closely related to the interaction of metal-rich solutions of magmatic origin with seawater.

Hydrothermal deposits sampled from Loihi seamount are enriched in iron, copper and cadmium and depleted in manganese. These deposits were probably formed by precipitation from cooling vent fluids or during cooling and oxidation of high temperature polymetallic sulfide assemblages. 50/

50/ Malahoff, A., G. McMurtry, J.C. Wiltshire, and Yeh Hsueh-wen. Geology and Chemistry of Hydrothermal Deposits from Loihi, The Latest Active Submarine Volcano of the Hawaiian "Hot Spot", Hawaii Institute of Geophysics Contribution.

V. ISSUES OF CONGRESSIONAL INTEREST

The discovery of what may prove to be a new source of metals from the marine environment raises a number of issues, not all of which are limited to the development of polymetallic sulfide deposits. In the broadest sense, the issue may be addressed as a question of jurisdiction over marine resources not previously identified in domestic legislation or international agreements. Of the legal framework that exists, some basic questions may be asked:

- To what extent does the domestic and international legal framework pertain to or include marine polymetallic sulfide deposits?
- How adequately does it address any of the needs that are unique to polymetallic sulfide minerals development?
- Is it appropriate to modify the existing domestic legal framework to include marine polymetallic sulfide deposits?

The following section is not intended to be a thorough review of the legal framework but rather background for indentifying some of the issues that may be of interest or concern to Congress.

IS THE EXISTING DOMESTIC LEGAL FRAMEWORK ADEQUATE?

When legislation governing development of the Outer Continental Shelf and deepsea minerals was enacted, ocean floor polymetallic sulfides were not an issue. These hydrothermal marine minerals are not addressed specifically in either piece of legislation; there is some question regarding the suitability of the existing legislation for polymetallic sulfides development.

Deep Seabed Hard Mineral Resources Act of 1980 (P.L. 96-283)

The Deep Seabed Hard Mineral Resources Act defines a legal framework for mining manganese nodules by U.S. nationals on the deep ocean floor beyond the limits of national jurisdiction. "Hard mineral resource means any deposit or accretion on, or just below, the surface of the deep seabed of nodules which include one or more minerals, at least one of which contains manganese, nickel, cobalt, or copper." There is a question over whether or not this definition includes polymetallic sulfides which are found in massive form along rock fractures or as "chimneys" or "stacks". Although there are similarities between the two types of deposits because of their location in deep water typically beyond the continental shelf, there are major differences. If the definition were to be modified to include polymetallic sulfides, it is not clear that other sections of the legislation would be appropriate for mining the sulfides. For example, the definition of deep seabed includes the subsoil only to a depth of ten meters, thus presumably excluding or arbitrarily limiting polymetallic sulfide deposits which are found to be much deeper.

Outer Continental Shelf Lands Act of 1953 (P.L. 83-212) and 1978 Amendments, (P.L. 95-372)

Among its provisions, the OCS Lands Act governs exploitation of mineral resources on the Outer Continental Shelf of the United States. The Act does not define the term "Outer Continental Shelf" geologically, but states that the term means "all submerged lands lying seaward and outside the area of

land beneath navigable waters and of which the subsoil and seabed appertain to the United States and are subject to its jurisdiction and control." Although the continental shelf is a geologically recognizable feature, the outer boundary of the "submerged lands" is not defined in the Act. In any event, it would appear likely that the Act would require amendment if it were to include polymetallic sulfide deposits beyond the shelf. Moreover, while the Act specifically addresses hard minerals development, the regulations necessary to implement the hard minerals development have never been established. The Act assumes such measures as: royalty fees payable to the Federal Government, competitive bidding, and other stipulations which were designed for petroleum development by a mature offshore oil industry and, therefore, may not be appropriate for the innovation of deep ocean hard mineral exploitation.

UNILATERAL AND INTERNATIONAL AGREEMENTS

The location of the polymetallic sulfide deposits, within and beyond 200-mile coastal zone, necessitates consideration of the international aspects of jurisdiction and regulation of resources recovery. Several types of legal actions are summarized. Perhaps the most obvious is that of the Law of the Sea Treaty negotiations and text and how these may address or effect polymetallic sulfide development. As an example of a working multinational marine mineral development agreement, the Red Sea Commission is discussed. Finally, a brief description of the Truman Proclamation illustrates the wide range of arrangements that have been considered in the question of ocean resource development.

Common Heritage of Mankind

The United Nations General Assembly, in 1970, adopted a Declaration of Principles that proclaimed that the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction (also referred to as the international area) were the common heritage of mankind. The year before, it 1969, the Assembly had declared that, pending the establishment of an international regime, States were bound to refrain from all activities of exploitation of the resources of this international area.

Some nations interpret these two General Assembly resolutions as legally binding and argue that, without a treaty, there can be no recovery activities in the international area. Thus, they would argue that recovery of polymetallic sulfides from the international area could only be possible within the regime established in the Law of the Sea Convention, once it enters into force, and only by parties to that treaty.

Other nations, including the United States, maintain that the Assembly resolutions were not legally binding and that in the absence of a Law of the Sea Convention, there is a high seas freedom under the present High Seas Convention to recover resources from the international area. Thus, the United States maintains that in the absence of a regime specifically directed to ocean mining, recovery of these minerals can proceed.

Law of the Sea Negotiations

The Law of the Sea Conference that has been meeting since December 1973 is in the process of negotiating a treaty that would, among other things,

establish a system of 200-mile exclusive national economic zones (EEZ) and an international regime for the exploration and exploitation of resources in the area of the oceans beyond national jurisdiction.

Under the EEZ currently envisioned by the draft treaty, the coastal nation would have "sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources" within 200 miles of its coast. Thus, under the proposed treaty, the coastal nation would have jurisdiction over the polymetallic sulfides found within a 200-mile EEZ.

Although it might be argued that the treaty provisions, for access to resources in the area beyond national jurisdiction were drafted primarily or exclusively, depending on one's perspective, with manganese nodules in mind, article 137 of the current text of the treaty provides that there shall be no claim, acquisition, or exercise of rights with respect to minerals in the international area except in accordance with the Law of the Sea Convention. Thus, access to polymetallic sulfides beyond 200 miles would be subject to the provisions of a Law of the Sea Convention to those nations holding the view that the Law of the Sea Convention is the only regime applicable. This is one of the issues of concern to the current Administration, as it considers seeking further treaty changes.

Red Sea Commission

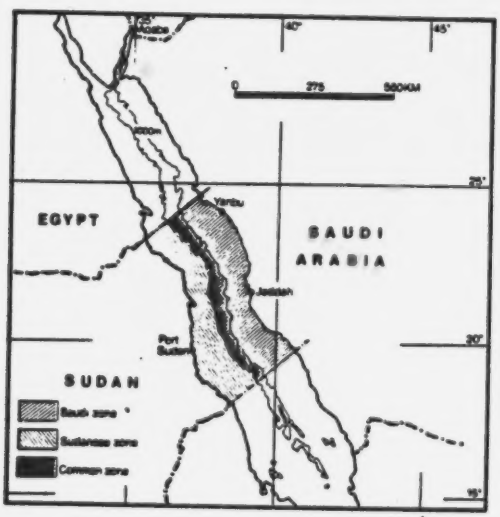
In a time when deep sea mining seems plagued by the stormy waters of stressful negotiation among nations, the opportunities for development of the Red Sea mineral resources appear relatively calm. A factor which favors the prospect of expeditious development in the Red Sea is the Saudi Arabia-Sudanese agreement, concluded in 1974, to hold joint equal and exclusive

sovereign rights to economic development of a designated common zone in the central Red Sea below water depth of 1,000 meters (3,280 feet) (figure V-1). 51/

51/ Shanks, Economic and Exploration Significance of Red Sea Metalliferous Brine Deposits, 1982.

The joint Red Sea Commission has been sponsoring research and development on recovery of the mineralized sediments since 1975.

FIGURE V-1. Economic Rights Zones in the Red Sea Between Sudan and Saudi Arabia.



Source: Mining Magazine, Aug. 1981.

In addition to the advantages of a joint agreement, there is money available for development. Saudi Arabia, posessing vast financial resources but primarily dependent on export of crude oil, is anxious to expand its economic resource base. Sudan, facing financial problems, does not have funds to spare for the Red Sea project. Saudi Arabia is financing the entire venture. Under the agreement, Saudi Arabia would recover its initial outlay after commercial production begins, and then Sudan would share in the economic return from the venture. 52/

52/ Georghiou and Ford, Arab Silver from the Red Sea Mud, 1981.

The project would further the economic development of both countries and serves as an example of cooperation between two Islamic nations. These mutual interests have pre-empted possible legal disputes over rights to the resource. The arrangements and advantages of the agreement have been described as follows:

> In essence, each country has exclusive rights between its coastline and the 1,000-meter contour. Between those two outer limits the countries declared a common zone in which they share the rights. This zone includes all the main brine pools. A median line drawn between the two countries would place the pools on the Sudanese side, but there now seems little that Sudan would gain from claiming them. And if the long awaited treaty being prepared by the United Nations Conference on the Law of the Sea is agreed . . . its recognition of 200 mile exclusive economic zones around coastal states will leave the fate of the riches of the Red Sea to bilateral agreement. 53/

53/ Ibid.

Presidential Proclamation

In 1945, a policy proclamation on ocean affairs, issued by President Harry S. Truman, stated that the Government of the United States "regards the natural resources of the subsoil and seabed of the Continental Shelf beneath the high seas contiguous to the coasts of the United States and appertaining to the United States, subject to its jurisdiction and control" on the basis of geologic unity of the continent and adjacent shelf. Although boundary lines were not specifically delineated in the proclamation, an accompanying news release set the limit at 100 fathoms (600 feet). The Truman proclamation and the claim of the United States was subsequently recognized by the Geneva Convention of the Continental Shelf, although this is now somewhat uncertain due to the Third U.N. Conference on the Law of the Sea. It has been suggested that similar more specific proclamation might be made regarding jurisdiction over hard mineral resources within a 200 mile limit. While this may establish a domestic regulatory framework, recognition beyond the United States would likely be limited. Further, presumably some U.S. interests would not necessarily be well served if other nations took equivalent actions.

ENVIRONMENTAL ISSUES OF DEEP OCEAN MINING

As every activity of human beings in their environment has an impact, deep sea mining will have some effect on the environment of the ocean floor as well as on the entire water column through which the mining system passes. The need to better define the magnitude of this impact has been a concern raised by many. Previous research, primarily related to ferromanganese

nodules, indicated that the overall impact may be negligible although locally adverse disturbances may be expected.

Early Research

Investigations to determine the extent of the environmental impact of ferromanganese nodule mining began over a decade ago. In the summer of 1970, at the invitation of Deepsea Ventures, Inc., a group of marine scientists under the direction of Dr. Oswald A. Roels of the Lamont-Doherty Geological Observatory observed a pilot hudraulic nodule mining test on the Blake Plateau in the Atlantic. In this test, studies were made on the mixing of the bottom water discharged into the surface waters and its effect on dissolved oxygen concentration and phytoplankton growth. No significant adverse effects were found. In July 1972 a cruise aboard the R/V Robert D. Conrad was undertaken to determine the physical, chemical, and biological conditions in a manganese nodule province on the Bermuda Rise. The bottom dwelling fauna were found to be very sparse in this area.

In August and September 1972 investigators under support from the National Oceanic and Atmospheric (NOAA) monitored a test of a Continuous Line Bucker (CLB) nodule mining system in a siliceous ooze province in the North Pacific. Physical, chemical, and biological conditions of the water column were observed and bottom dwelling fauna (benthos) were sampled before, during, and after the mining operation. In addition cores and photographs were taken of the bottom. The May 1973 report by NOAA on this study stated that preliminary investigations provided information on what was

needed for an effective evaluation of deep sea mining, and suggested a three-phase environmental assessment study to make the evaluation. 54/ In 1974

54/ U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, The Environmental Impact of Deep-Sea Mining, Progress Report, NOAA Technical Report ERL 290-OD 11, May 1973, 185 p.

the Department of the Interior prepared a draft Environmental Impact Statement (EIS) to support the law of the sea negotiations. The draft was never made into a final EIS because the necessary basic data were not available. 55/

55/ U.S. General Accounting Office, Deep Ocean Mining Environmental Study--Information and Issues, PSAD-76-135, Sept. 21, 1976, 20 p.

In May 1974 NOAA announced that it would implement a Deep Ocean Mining Environment Study (DOMES) project to develop the information needed to prepare an adequate EIS of deep ocean mining.

The DOMES Program

NOAA requested funding for a DOMES pilot study to begin in FY 1975. While the request was approved in concept, budgetary constraints did not allow funds until FY 1976. NOAA began the Deep Ocean Mining Environmental Study program in 1975 as a comprehensive five-year research effort to be carried out in two phases. Phase I had the objectives of establishing environmental baseline information in typical nodule mining areas, developing a preliminary predictive capability for determining potential impacts of

nodule recovery, and developing the information base for preparation of environmental regulations. Phase II (DOMES II) involved monitoring pilot-scale mining tests conducted by industry in 1978. The objectives of this phase were to observe actual environmental effects, improve predictive capability, and to refine or modify the information base upon which subsequent regulations would be based.

The DOMES project showed that many of the activities that initially raised concerns about deep seabed mining were unlikely to have a significant adverse environmental impact. 56/ The environmental impacts identified in

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56/ U.S. Department of Commerce. National Oceanic and Atmospheric Administration. Deep Seabed Mining, Report to Congress, Dec. 1981. p. 26.

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the DOMES program and an assessment of their status is given in table V-1. Although the activities identified in table V-1 appear to pose no immediate threat to the environment, further monitoring during actual mining operations will be required. Mapping and sampling will have no adverse environmental impact.

Pursuant to the Deep Seabed Hard Mineral Resources Act (P.L. 96-283) and the National Environmental Policy Act (NEPA), NOAA prepared a programmatic environmental impact statement (PEIS) to assess the environmental impact of exploration for and commercial recovery of manganese nodules from the deep seabed. Research conducted under the DOMES program provided the

framework for this impact statement. The final draft of the PEIS was filed with the Environmental Protection Agency on September 18, 1981. 57/

57/ U.S. Department of Commerce. National Oceanic and Atmospheric Administration. Deep Seabed Mining. Final Programmatic Environmental Impact Statement, vols. I and II, Sept. 1981.

Comparative Impacts of Mining Hydrothermal Deposits Versus Nodules

The DOMES program identified three potentially adverse effects of deep seabed nodule mining. These are the destruction of benthos in and near the collector, blanketing of benthos and the dilution of its food supply away from the mine site, and the surface plume effect on fish larvae. 58/

58/ NOAA, Deep Seabed Mining, Report to Congress, Dec. 1981, p. 26.

While the marine environment of hydrothermal vent areas is significantly different from the deep sea nodule areas, some impacts of ocean mining may be common to both areas. For example, the inherent physical disturbance of an ocean mining operation would be expected to cause destruction of the benthos in the way of the mining system. The marine biota in active vent areas described in chapter II is varied and unusual. However, because of the severe hazard of mining an active vent area, potential recovery of hydrothermal vent deposits would only be expected to occur in inactive vent areas. In these areas, the cessation of hydrothermal activity would have already allowed the restoration of a normal ocean environment and consequently cause

the extinction of the exotic, warm vent-dependent life forms. Thus, the mining of hydrothermal deposits would be expected to be destructive to what may be considered a fairly normal range of biota that would be expected to be found in the immediate vicinity of the mining operation. This destruction would occur from the breaking and physical removal of the hard mineral deposits in the mining area.

The second potentially adverse impact of nodule mining, smothering of benthos and the dilution of its food supply away from the mine site, could also occur from the mining of hydrothermal deposits. The extent of this impact and also of the surface plume effect depends primarily on the amount, size, and nature of the fine-grained material associated with the mining operation. In monitoring nodule mining, NOAA found "although the destruction of the benthos by the collector is clearly adverse, neither its impact nor that of the blanketing appears to be significant." 59/

59/ Ibid., p. 28.

The impact of the plume on the survival and behavior of fish larvae would require monitoring of an actual mining operation. It is possible that there could be a fairly minimal plume from mining hydrothermal deposits depending on the method of transporting the material to the surface and on whether there were little or no gangue or non-orebearing sediment to be removed.

As required by the Deep Seabed Hard Mineral Resources Act, NOAA has developed a five-year research plan which emphasizes the three main environmental concerns and assumes that they can be resolved by a combination of

industry self-monitoring and government research. The law specifically identifies elements to be included in the research plan, such as natural diversity of the deep seabed biota, life histories of major organisms likely to be impacted, long-and short-term effects of commercial recovery on deep seabed biota, and effects of seabed processing. Should mining of hydrothermal deposits become of commercial interest, much of the experience and expertise gained in monitoring and predicting environmental impacts of nodule mining should be transferable to hydrothermal deposits.

LEGISLATIVE CONSIDERATIONS

The Congress may decide to respond to the uncertain jurisdictional and regulatory issues surrounding hydrothermal marine minerals development through legislative action. A number of approaches have been suggested; two are cited here as examples.

Exclusive Economic Zone

One form of response to questions of jurisdiction over hard mineral resources on the Outer Continental Shelf or beyond could be for the United States to establish an Economic Zone or Exclusive Economic Zone. If such action were desired by Congress, it could be accomplished in the form of legislation which might be related, as a precedent, to the Fisheries Conservation and Management Act of 1976 which extended U.S. fisheries management and jurisdiction to 200 nautical miles. In this regard, 54 nations

had established 200 nautical mile economic zones as of May 1981. These nations are identified in table V-2 along with 14 additional nations which have unilaterally claimed 200-mile territorial seas, claims unlikely to be upheld under current international law.

Amendments to the Deep Seabed Hard Mineral Resources Act

Domestic legislation for ocean mining exists but it was designed for mining manganese nodules which differ from hydrothermal marine minerals in many aspects. Major differences include: location, form, composition, size and nature of deposit, and depth. The definition in the Deep Seabed Hard Mineral Resources Act could be modified to include polymetallic sulfides, however, other aspects of the legislation may not be appropriate for mining hydrothermal deposits. It is likely that the existing legislation would have to be modified extensively to be applicable to both ferromanganese nodules and polymetallic sulfides.

TABLE V-2. National Maritime Claims

200 Nautical-Mile Territorial Sea*

Argentina	El Salvador	Panama
Benin	Ghana	Peru
Brazil	Liberia	Sierra Leone
Congo	Nicaragua	Somalia
Ecuador		Uruguay

* Overflight and navigation permitted beyond 12 nautical miles.

200 Nautical-Mile Economic Zone

Bangladesh	Iceland	Norway
Barbados	India	Oman
Burma	Indonesia	Pakistan
Cape Verde	Ivory Coast	Papua New Guinea
Colombia	Kampuchea	Philippines
Comoros	Kenya	Portugal
Costa Rica	Korea, North	Sao Tome and Principe
Cuba	Madagascar	Seychelles
Djibouti	Maldives	Spain
Dominican Republic	Malaysia	Sri Lanka
France	Mauritania	Suriname
Grenada	Mauritius	Thailand
Guatemala	Mexico	Togo
Guinea	Morocco	United Arab Emirates
Guinea-Bissau	Mozambique	Vanuatu
Guyana	Nauru	Venezuela
Haiti	New Zealand	Vietnam
Honduras	Nigeria	Yemen (Aden)

Note: Boundary conditions with neighboring states prevent many states from extending their economic zones to a full 200 nautical miles.

From: Limits in the Seas, No. 36--4th revision, National Claims to Maritime Jurisdiction. Edited and Compiled by Robert W. Smith, Office of the Geographer, Bureau of Intelligence and Research, U.S. Dept. of State, May 1, 1981, 177 p.

APPENDIX I

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TABLE V-1. Deep Seabed Mining Perturbations and Environmental Impact Concerns

		BENTHIC IMPACT		SURFACE DISCHARGE	
	STATUS OF CONCERNS*	COLLECTOR CONTACT	BENTHIC PLUME	PARTICULATES	DISSOLVED SUBSTANCES
CONCERNS WITHOUT POTENTIAL FOR SIGNIFICANT OR ADVERSE IMPACTS	Low Probability of Impacts	Light from collector	Nutrient or trace metal increase	Bacteria growth deplete oxygen	Trace metals effects on phytoplankton
			Oxygen demand	Alter phytoplankton species composition	Nutrient increase cause phytoplankton blooms
				Affect fish	
				Zooplankton mortality and species composition and abundance changes in plume	Nitrite caused embolisms
				Trace metals entry into food web	
	Impacts Not Yet Resolved	Not Applicable	Not applicable	Pycnocline accumulation	Not applicable
	Potentially Beneficial Effects	Additional food supply for bottom scavengers	Not applicable	Bacteria increase food supply for zooplankton	Not applicable
				Filterfeeding zooplankton fecal pellets clean up plume	
	Certain Impact Without Significant Adverse Effects	Not applicable	Not applicable	Increased turbidity reduce productivity	Not applicable
CONCERNS WITH POTENTIAL FOR SIGNIFICANT OR ADVERSE IMPACTS	Certain Impacts	Destroy benthos in and near track	Not applicable	Not applicable	Not applicable
	Unresolved Impacts	Not applicable	Blanket benthos; dilute food supply away from mine-site sub-areas	Affect fish larvae	Not applicable

*NOTE: Status of concerns is to be verified during demonstration-scale mining system tests, prior to commercial mining

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APPENDIX II

Assumptions for Calculating the Economics of a Nodule Mining Project

Median Manganese Nodule Mine

Base Year	1981 $
Units	mt = metric tonnes (d=day)
Start of Construction	Year 1 1985
Start of Production	Year 4 1.5 million dmt
Production (20 years)	Years 5-25 3 million dmtpy
Moisture Content	30 percent

Product Profile:

Metals	(Dry) Ore Content %	Recovery %	Annual Saleable dmt	Form	Price 1981$/lb.	Required Price* 1981$/lb.	Sales Proceeds 1981$MM	Sales Proceeds %
Ni	1.5%	90%	40,500	Granules	$ 3.20	$3.85	$285.7	44%
Cu	1.3	90	35,100	Cathodes	1.10	1.74	85.1	13
Co	0.25	75	5,625	Electro	10.00	12-27.50	124.0	19
Mn	.29	80	696,000	Crude	0.10	---	153.4	24
							648.2	100%

* Required for new greenfield land-based mine production.

Investment Profile (1981 $ million):

Exploration and R&D (Two sites)	$150
Mining System (Two ships)	235
Port, Process Plant, Pre-Production	550
Working Capital (4 months Op-Costs)	95
Replacement Capex (Annual)	35

Expenditure Year 1-$132; Year 1-$308; Year 3-$396; Year 4-$44

Operating Costs (1981 $/dmt ore):

Exploration/Development	$ 1.70
Mining	20.70
Ocean Freight (charter)	11.20
Processing	54.90
Administration	2.30
Selling Costs, Misc.	4.50
Total	$95.30

Loan Profile

Debt is 50 percent on capital costs and working capital, plus capitalized interest. All-in interest expense of 15 percent. R&D covered by 100 percent equity.

LOST Cash Flow Profile

Capital Cost and Sales Price Escalation	1981-1987	12% p.a.
	1988-1992	10% p.a.
	1993-1998	8% p.a.

10-year, Straight-Line Depreciation/Amortization.
Tax is 50 percent of Net Profit Less "Portion of Attributable Net Proceeds" payable to the Authority.

UN LOST Parameters (Appendix III, Article 13 of 9/80 Treaty Draft)

Interest on Unrecovered Development Costs	10% p.a.
Annual Fixed Fee	$1 million

Combination "Financial Contribution" (Taxes):

	1st Production Period	2nd Production Period*
"Production Charge"	2%	4%

* Occurs when "Unsecured Development Costs" reduced to zero.
% of "Attributable Net Proceeds
(i.e. 25%** of "Net Proceeds")

	1st Production Period	2nd Production Period
ROI between 0 and 10%	35%	40%
ROI between 10% and 20%	42.5%	50%
ROI greater than 20%	50%	70%

** This may be higher--to some unknown floor set by the Authority per A III 13.6 (e)
"Development Costs" recovered over 10 years, straight line. Mining Sector "Unrecovered Development Costs" is ratio of 235:1050 of total preproduction Unrecovered Development Costs. During Production, 50 percent of replacement Capex is for Mining Sector.

US Cashflow Profile

Removal Tax is 3.75 percent of 20 percent of Gross Proceeds. Depreciation/Amortization over 5 years for US tax purposes. Tax Rate of 48 percent All-in. Annual NCF and Investment reduced to 1981$ and Investment is original $1,050 million per Investment Profile above.

Source: Tinsley, C.R. Financing of Deep Ocean Mining. Statement (unpub.) presented to the Ad Hoc Panel on Marine Minerals of the National Advisory Committee on Oceans and Atmosphere, Sept. 24, 1981.

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